APPLICATION OF LINEAR PROGRAMMING FOR FEED FORMULATION

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Mumbai-400061

By

DIPANKAR GHOSH, B.F.Sc.
(MC-74)

भा कृ अनु प
ICAR

CENTRAL MARINE FISHERIES RESEARCH INSTITUTE
Indian Council of Agricultural Research
COCHIN - 682014
INDIA

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केंद्रीय समुद्री मात्स्यिकी अनुसंधान संस्थान
पोस्ट बॉक्स सं 1603, एरणाकुलम, कोचीन-682 014

भा कृ अनु प
ICAR

CENTRAL MARINE FISHERIES RESEARCH INSTITUTE
POST BOX No 1603, ERNAKULAM, COCHIN- 682 014
(भारतीय कृषि अनुसंधान परिषद)
(Indian Council of Agricultural Research)

Phone (Off) : 394867/....Ext. 391407
Telegram : CADALMIN EKM
Telex : 0885-6435 MFRI IN
Fax : 0484-394909
E-mail : mdcmfri@md2.vsnl.net.in

Dated 30 JUNE, 2003

CERTIFICATE

Certified that the dissertation entitled **"APPLICATION OF LINEAR PROGRAMMING FOR FEED FORMULATION"** is a record of independent bonafide research work carried out by **Mr. Dipankar Ghosh** (MC-74) during the period of study from September 2001 to August 2003 under our supervision and guidance for the degree of **Master of Fisheries science (Mariculture)** at the Central Marine Fisheries Research Institute, Kochi, and that the dissertation has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title.

Major Advisor/chairman

Dr. T. V. Sathianandan
Scientist (Sr. Scale)
Fishery Resources
Assessment Division

Advisory committee

Dr. M. Srinath
(Co-chairman)
Principal Scientist and
Head, Fishery Resources
Assessment Division

Dr. (Mrs.) Somy Kuriakose
(Member)
Scientist
Fishery Resources
Assessment Division

DECLARATION

I hereby declare that the thesis entitled "**APPLICATION OF LINEAR PROGRAMMING FOR FEED FORMULATION**" is an authentic record of my own research work and that no part thereof has been presented for the award of any degree, diploma, associateship, fellowship or any other similar title.

Dipankar Ghosh

30th June, 2003 M. F. Sc student (MC-74)

Cochin Central Marine Fisheries Research Institute

THIS WORK IS

DEDICATED TO

AQUACULTURE INDUSTRIES AND AQUACULTURISTS

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सारांश

मछली पालन में, प्रोटीन, लिपिड कार्बोहाइड्रेट, फाइबर, एमिनो आसिड्स, पाच्य ऊर्जा, बिटामिन्स एवं खनिजों से संतुलित कृत्रिम खाद्य का उपयोग अनिवार्य है होता है. खाद्य के रूपायन में यह अत्यंत आवश्यक है कि सबसे कम लागत में पौष्टिक एवं सुसंतुलित खाद्य के उत्पादन केलिए सही एवं अनुकूलतम अनुपात में विभिन्न खाद्य संघटकों, जिनमें उपर्युक्त पौष्टिक आवश्यकताएं मौजूद हैं, को मिलाया जाना है.

इस अध्ययन में , पुलि झींगा (*पेनिअस मोनोडोन*) किशोर, स्काम्पी (*माक्रोब्राशियम रोसेनबर्गी*) किशोर, रोहू (*लैबियो रोहिता*) पोना, शिंगटी पोना, मिल्कफिश (चैनोस चैनोस) पोना, तिलापिया पोना, एशियन समुद्री बैस (लैटस कैलकारिफर) पोना एवं ग्रूपर पोना केलिए उनकी पौष्टिक आवश्यकताओं को विभेदों के रूप में लेकर कोच्ची, टूटिकोरिन, तथा भुवनेश्वर में पच्चीस खाद्य संघटकों के बाज़ार भाव पर विचार करते हुए लीनीयर प्रोग्रामिंग द्वारा अनुकूल खाद्य रूपायन निर्धारित किया गया है. पुलि झींगा किशोरों, जयन्ट मीठा पानी झींगा किशोरों तथा रोहू पोना केलिए एमिनोआसिड आवश्यकता पर विचार नहीं करते हुए. लीनियर प्रोग्रामिंग समस्या में लगाए हुए विभेदों में परिवर्तन करके खाद्य रूपायन निर्धारित करने का प्रयास भी किया गया. इन मछली जातियों केलिए आवश्यक सोलह पोषकों की पौष्टिक आवश्यकताएं विश्लेषण केलिए संग्रहित किया गया.

पांच खाद्य संघटकों को मिलाकर *पी. मोनोडो* के किशोरों केलिए लीनियर प्रोग्रामिंग द्वारा रूपाइत खाद्य का बाज़ार भाव कोच्ची में रु. 37.32, टूटिकोरिन में रु. 42.46 और भुवनेश्वर में रु.29.84 रहा. जब दस अनिवार्य एमिनोआसिड विभोदों को निकालकर विभेद परिवर्तन करके चार संघटकों युक्त खाद्य का रूपायन किया, तब बाज़ार भाव कोच्ची एवं टूटिकोरिन में क्रमशः रु. 7.40 तथा रु. 5.87 रहा और पांच संघटकों युक्त खाद्य केलिए भुवनेश्वर में बाज़ार भाव रु. 4.05 रहा. इसी प्रकार इन तीनों स्थानों में खाद्य संघटकों के बाज़ार भाव के आधार पर अन्य सात मछली जातियों केलिए भी खाद्य का रूपायन किया गया. खाद्य रूपायन केलिए विचार किए गए 16 पोषकों के खाद्य सूत्रों के पौष्टिक स्तरों का कंप्यूटिंग किया गया है.

ABSTRACT

The use of artificial feed balanced in protein, lipid, carbohydrate, fibre, amino-acids, digestible energy, vitamins and minerals is very essential in fish farming. In the formulation of feed it is necessary to determine exact optimum proportions of different feed ingredients, which meets the above nutritional requirements, to be mixed to produce a nutritionally well-balanced feed at the least possible cost.

In this study optimum feed formulations are determined, as solutions of linear programming, for Tiger shrimp (*Penaeus monodon*) juveniles, Scampi (*Macrobrachium rosenbergii*) juveniles, Rohu (*Labeo rohita*) fry, Catfish fry, Milkfish (*Chanos chanos*) fry, Tilapia fry, Asian sea bass (*Lates calcarifer*) fry and Grouper fry with their nutritional requirements as constraints and considering market prices of twenty five feed ingredients at Kochi, Tuticorin and Bhubaneswar. For Tiger shrimp juveniles, giant freshwater prawn juveniles and Rohu fry feed formulations without considering the essential amino acid requirements were also attempted by relaxing the imposed constraints in the linear programming problem. Nutritional requirements of these species in terms of sixteen nutrients required for the analysis were collected from literature.

Feed formulated through linear programming for juveniles of *P. monodon* was composed of five feed ingredients costing Rs. 37.32 at Kochi market price, Rs. 42.46 at Tuticorin market price and Rs. 29.84 at Bhubaneswar market price. When the constraints were relaxed by removing ten essential amino acid constraints, the formulated feed was composed of four ingredients costing Rs. 7.40 and Rs. 5.87 respectively for Kochi and Tuticorin market prices and five ingredients costing Rs. 4.05 for market price of Bhubaneswar. Feed formulations were also obtained in a similar manner for the other seven species based on market prices of the feed ingredients at the three places. The nutritional status of the feed formulae in terms of the 16 nutrients considered was computed for each of the feed formulations obtained.

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1. INTRODUCTION

Aquaculture, the farming of aquatic animals and plants, has been the world's fastest growing food production system in the past decade with an average compound growth rate of 11.6% per year since 1984, compared to the growth of 3.5% per year for terrestrial livestock meat production and 1.8% per year for capture fisheries production. Aquaculture is a feed-based industry, with over 60% of operational cost coming from feed source. With shifting from extensive to semi-intensive or intensive farming, the dependence of farmed animals on exogenous feed supply is more and more pronounced, as the standing crop of culture species exceeds the "natural feeding capacity" of the pond. Modified extensive and semi-intensive culture systems depend primarily on steady supply of supplementary artificial feeds. The use of artificial feed balanced in protein, lipid, carbohydrate, fibre, amino-acids, digestible energy, vitamins and mineral is an obvious approach to realise genetic potential of the animal for survival, immunity, growth and reproduction. Aquaculture nutrition is a vital area for maintaining the sustainability of aquaculture industry. There is an emerging need to produce fish in quality and quantity with increasing demand in the global market.

Fish feed formulation is the process which has to take into account the objective of achieving optimal fish production, consumer preference and net benefits that can be earned by an aqua culturist and the purpose here is to determine the types and quantities of ingredients to be mixed to produce a complete feed at possible low cost. The fish species under culture should be fed with an exogenous feed that imitates as far as possible the nutrient levels in their natural food. Such a feed is unlikely to be found in a single source of ingredient but can be achieved by mixing more than one material in a balanced way. The feed preparation thus becomes a major consideration for the process of combining different feed ingredients in a suitable way so as to achieve the specific goals of culture fish production. There are practical goals like rapid growth rate, successful reproduction and experimental goals such as induction of a vitamin deficiency or establishment of a minimum dietary nutrient requirement. Several considerations, therefore, need to be taken into account, as the feed should be nutritionally viable, physically acceptable, practically applicable and economically feasible. To achieve optimal production most feed formulations fall between two extremes. One extreme is to base the formulation primarily on cost and chemical composition, producing a feed that is less expensive than other feeds. The other extreme is to base the formulation primarily on nutritional value thereby producing more expensive feed that is more productive, thus requiring less feed per unit of fish production. But the most favoured one is to determine exact optimum proportions of different feed ingredients, which meets the necessary nutritional requirements for protein, lipid, carbohydrate, fibre, essential amino acids, calcium and phosphorus ratio, digestible energy, etc. for a particular fish species so that the total unit cost of the feed formulated will be the least possible. This is being done through Linear Programming Technique.

Linear programming would allow a number of constraints, maximum or minimum levels of nutrient requirement and ingredient inclusion to be set based upon cost and nutritive values. It enables the nutritionists to compare a wide range of feedstuffs to determine which will blend together to provide the desired nutrient levels at the lowest possible cost without bias towards any ingredient. In Linear programming, the requirements have to be measured and expressed in numerical terms. To get a Linear programming solution for feed formulation, the information must be supplied are (1) a list of ingredients that are available for use in the feed and their cost. (2) The nutrient contents for each of the ingredients. (3) The nutritional requirements of the species in terms of minimum, maximum or exact quantities needed, and (4) any physical or non-nutritive limitation which might be imposed because of ingredient characteristics, limitation of supply, effects on feed mixture, toxic factors and ability of feed to be pelleted. There are certain attributes such as palatability or acceptability on which it is difficult to place a numerical value. The most effective nutrient values will be those that accurately reflect the biological availability of the ingredients. Linear programming is one of the optimisation techniques in mathematics wherein an objective function, in terms of n variables; say $x_1, x_2, \ldots, x_n$ of the linear form $c_1x_1 + c_2x_2 + \ldots + c_nx_n$ is optimised (minimized or maximized) subject to a set of k linear constraints formulated.

$$\begin{matrix} a_{11}x_1 & + a_{12}x_2 & + \ldots + & a_{1n}x_n & = b_1 \\ a_{21}x_1 & + a_{22}x_2 & + \ldots + & a_{2n}x_n & = b_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ a_{k1}x_1 & + a_{k2}x_2 & + \ldots + & a_{kn}x_n & = b_k \end{matrix}$$

Using matrix algebra this is denoted as

$\min\limits_{x} c'x$ Such that

$Ax = b$ And $l \le x \le u$

Where, $c' = (c_1, \ldots, c_n), x' = (x_1, \ldots, x_n), l' = (l_1, \ldots, l_n), u' = (u_1, \ldots, u_n), A = (a_{ij})_{k \times n}$

Also some of the equations may hold "$\le$"instead of "$=$" sign and upper bound and lower bound are set for the values of x_i's. In the context of finding an optimum feed formulation, the Linear programming set up is the following. Let, $b_1, b_2, \ldots, b_k$ are the requirements for a species with regards to k essential/ nonessential nutrients (some may be minimum/maximum levels). Suppose there are n numbers of feed ingredients available for preparation of the feed composition that are the sources for the k nutrients. Let the proportion of the i^{th} nutrient available in the j^{th} ingredient is denoted by a_{ij}, then we get the k equations of constraints as $a_{i1}x_1 + a_{i2}x_2 + \ldots + a_{in}x_n = b_i$ and for the k nutrients we get k such equations of constraints, where $x_1, x_2, \ldots, x_n$ are the proportions of n feed ingredients. Now if $c_1, c_2, \ldots, c_n$ are the unit costs of the ingredients, the objective is to minimize

$c_1x_1 + c_2x_2 + ... + c_nx_n$ which is the total cost subject to the above mentioned k constraints.

Sometimes, the Linear programming solution may not provide right decisions from economic point of view. For example, nutrient requirements determined to achieve maximum growth rate using linear programming may not be the best from economic considerations. Relaxing nutrient constraints while still achieving acceptable lower growth may bring down feed cost.

The objective of the present study is to formulate nutritionally balanced feed for Tiger shrimp juveniles, Scampi juveniles, Rohu fry, Catfish fry, Milkfish fry, Tilapia fry, Asian sea bass fry and Grouper fry, based on their nutritional requirements, at the least possible cost considering market prices at three different places in the country.

2. REVIEW OF LITERATURE

Pinchuk (1970) used linear programming to optimize the exploitation of fish culture production resources in the Donetsk fishery group and to discover means for economizing on expenditures while maintaining the actual output volume of each district within Donetsk area. For eight production districts of the Donetsk fishery groups he presented objective function, constraints, inputs used, optimum values and item wise data on feeds, fertilizers, labour, fingerlings, electric power, and pond area.

David (1971) discussed about the purpose of linear programming model in checking growth methods, marketing analysis, checking the economics of buying and selling, economics of the size of fisheries and in checking the general fisheries profitability. He also described the nature of linear programming, the main principles involved and the results of the model's operation with an example of an intensive fish growth programming besides noting the future possibilities for using this model.

Drobny (1971) presented basic elements of linear programming while discussing about the applications of linear programming to water quality and water quantity problems. He placed emphasis on the elements of linear programming that make it a useful tool for analyzing water resource problems that render them amenable to meaningful analysis.

Low (1975) used linear programming for examining the implications of managing the major ground fish and crustaceans resources under exploitation to formulate a systematic approach to management of the resource and to gain insight to the management strategies, given any set of regulatory objectives.

Gates and Mueller (1975) presented an economic linear programming model to a closed system culture of salmonids considering factors like fish recruitment, market price patterns, fish size, growth ratios, and water temperature. They concluded that there was no single fish size at which it was economically optimum to sell fish under all conditions and that optimum temperature was influenced by the seasonality of sale prices. The effects of seasonality in prices depended on conditions of recruitment supply.

Mara (1976) applied dynamic linear programming for achieving minimum cost of the mechanical harvesting means of controlling water hyacinths (*Eichhornia crassipes*) in Florida. He developed the cost-minimizing linear programming model and applied to a hypothetical lake to determine the least-cost method and seasonal pattern of removal to attain specified levels of control.

Chow *et al.* (1978) made an attempt to describe the mechanisms of Linear programming in the formulation of fish feed using a standard software package (IBM MPSX) and common hardware (IBM 370), rather than discussing the fish feed formulation in the context of specific nutrients requirements of a particular species.

Barbieri and Cuzon (1980) discussed about the improved nutrient specification for diet formulation of penaeid rations using linear programming. They used linear programming techniques in order to set up a formula of shrimp diet considering an economic function. Nutrient constraints were determined, together with a selection of ingredients to match the main known nutritional requirements of the species *Penaeus japonicus*. By means of linear programming an optimum solution was found and the formula showed a cost reduction of nearly 30% by this method without any significant loss in growth performance of the species when the linear programming formulated diet was fed in that experiment.

Cho *et al.* (1985) mentioned about necessity of computerized least-cost fish feed formulation. Although some least-cost formulae had been employed successfully within the commercial aquaculture sector for several years, they emphasized more knowledge on digestibility coefficients and limitations of various feed ingredients; constraints (nutrients requirements), availability of these nutrients in different ingredients; and also on upper and lower ingredients level to formulate fish feed accurately in computer.

Engle (1987) developed a mixed integer linear programming model to select constrained optimum combinations of aquacultural production alternatives for limited-resource farmers. The model maximized production of fish and livestock for home consumption and cash income.

Akiyama *et al.* (1992) mentioned advantage of least cost feed formulation by computer for shrimp, which increases profits and results in the formulations of more nutritionally balanced feeds with no loss in production levels or shrimp performance. They described a number of limitations in utilizing least-cost feed formulations. They also listed out some least-cost restrictions for different nutrients in shrimp feed. They mentioned that because of little information available on shrimp nutritional requirements and on nutrient availability of different *ingredients, least-cost formulation of shrimp feeds had not been* routinely practiced unlike poultry and livestock feeds.

Lovell (1992) used linear programming for least-cost feed formulation for channel catfish (*Ictalurus punctatus.*). He used soybean meal, grain, fishmeal and meat and bone meal as main ingredients. Quantitative requirements for essential amino acids, minerals and most vitamins, and the ratio of energy-to-nutrients were determined for young fish and used for least-cost feed formulation, through linear programming.

Xiaomin and Yongfa (1993) used the method of linear programming in the process of compounding artificial feed for *Penaeus chinensis* with the analysis of limited nutrient constituents based on eighteen raw materials found most frequently on the East China coast, They showed that crude fat, crude ash, phosphorus, arginine and lysine were the limited nutrient constituents. Also, they found crude fiber and methionine to be the limited nutrient constituents of the prescriptions in which plant protein was the main type of protein.

Forsberg (1995) developed a multi-period linear programming model for production planning problems in determination of optimal number of smolts (seawater adapted young salmon) to recruit into grow-out system, estimation of population growth and production costs, and choosing optimal harvesting schedule in order to maximize profits from the operation. He applied this model for optimal management of size-structured farmed Atlantic salmon (*Salmo salar L.)* in land-based grow-out farms.

De Silva and Anderson (1995) discussed about the fish diet formulation using the least cost technique of linear programming and about the different data that are needed while formulating the nutritionally balanced diet for a particular species.

Gokulakrishnan and Bandyopadhyay (1995) designed three least cost feed formulae with linear programming model on the basis of nutritional (protein, fat, carbohydrate, ash and fibre) and energy requirements of *Penaeus monodon* with respect to proximate composition, energy, pellet diameter, true and bulk densities, settling rate and water stability. They showed that these feeds resembled some commercial shrimp feeds available in the market. Aquarium culture experiments with these feeds yielded feed conversion ratio similar to each other, but slightly higher than that of the commercial feed sample.

Grantham *et al.* (1995) used a linear programming model to examine the foraging strategy of the giant rams-horn snail, *Marisa cornuarietis,* based on its consumption of two aquatic macrophytes, *Ludwigia repens* and *Vallisneria americana*, in laboratory feeding experiments. They constructed a model for each of twenty-seven snails, incorporating estimates of daily energy requirement, digestive capacity, and feeding time of each individual and developed an index of foraging strategy to assist the evaluation of individual deviation from predicted optimal diets.

Nolet *et al.* (1995) used linear programming technique to test the diet choice of free-living beavers (*Castor fiber*) in the Biesbosch (The Netherlands) under different foraging goals, i.e. maximization of intake of energy, nitrogen, phosphorus and sodium, or minimization of feeding time. They used woody food, herbs and roots of monocots and assessed forage quality by measuring the dry matter, energy and mineral contents of the food plants as well as food intake rates, digestibility and metabolisability in captive beavers.

Khan *et al.* (1996) used linear programming techniques with the aim of setting up a dietary formula for *Mystus nemurus* utilizing an economic function. They selected ingredients based on their digestibility coefficients by *M. nemurus* and determined nutrient constraints to match the known nutritional requirements of the species. They expressed restrictions in a series of parametric linear equations with eight ingredients and twenty constraints and conducted growth tests for twelve weeks in controlled hatchery conditions. They found that despite the low cost, the diets were not economical due to lower specific growth rate (SGR), protein efficiency ratio (PER) and higher feed conversion ratio (FCR) for the species.

Jinping and Qifa (1996) analyzed a method available for optimizing aquatic fodder recipe, based on linear programming of linear objective function and linear subjected bind. They introduced an artificial intelligence technique and neural network system to overcome shortage occurred when non-linear programming was applied in practice.

Das *et al.* (1996) applied a least-cost linear programming package to determine the optimum inclusion levels of some locally available ingredients in the diet formulation for *Macrobrachium rosenbergii*. They formulated twelve pelleted diets containing protein and energy levels ranging from 30% protein, 400 kcal gross energy per 100 g diet to 40% protein and 520 kcal gross energy per 100 g diet. The essential amino acid constraints applied to the diets were based on the essential amino acid content of the eggs of brood stock *Macrobrachium rosenbergii*.

Bell and Trinidad (1996) identified the economic and ecological costs and benefits of two management strategies for mangrove conversion and sustainable exploitation and set up a linear programming problem for the maximization of total economic value from these strategies satisfying constraints pertaining to land, labour, availability of penaeid shrimp fry, rated capacity of processing plants and product demand.

Kouka and Engle (1996) developed a linear programming model to determine the profit maximizing effluent management strategies for varying levels of allowable effluent discharge from catfish culture. They discussed economic implications for varying policy alternatives.

Ahmed (1996) developed a bioeconomic model in a nonlinear programming framework to derive an operational model to estimate the net economic benefits obtainable from riverine fisheries of Bangladesh under an optimal management situation using demand and supply relations in the market. He obtained a linear programming solution using grid linearization and linear approximation techniques.

Trinidad and Garces (1996) used a constrained maximization linear programming approach to estimate fishery net revenues in San Miguel Bay, Philippines. They used three alternative scenarios and constraints including total allowable catch, catch distribution and crew wages, which resulted in increase of the net revenues on all scenarios.

Boll and Lanzer (1996) indicated that a maximal increase of 14% on fish farmers income could be achieved through species combination optimization using linear programming technique, in low intensity fish production systems used by small farmers in Santa Catarina (South Brazil) while evaluating the main bioeconomic constraints.

Pongthanapanich (1996) used Linear programming to determine a management guideline that would generate maximum net present value from mangrove utilization under various constraints imposed by local conditions along four coastal districts (Sikoa, Kantang, Yantakoaw and Palein) in Trang Province, Thailand.

Krishnan and Sharma (1996) used the linear programming matrix in multi-objective analysis of paddy-fishery enterprise system in the Kuttanad region of Kerala State (India) to develop a trade-off analysis between paddy and fishery systems via constraint approach and to suggest optimal operating policies for the Thaneermukhom salt-water barrage for maximizing returns from the region.

Herrick *et al.* (1997) developed a linear programming approach to assess short-run profitability, optimum access fees and net economic benefits for US tropical tuna purse seiners operating under the South Pacific Tuna Treaty. They indicated that there was potential for sizable short-run profits and net economic benefits after payment of an access fee equal to the imputed marginal value of the tuna harvested.

Mukhopadhyay (1997) explained computerized linear programming formulation and quadratic programming formulation techniques as different types of aqua feed formulations besides discussing about selection of ingredients. He listed out the information to be required while formulating fish feed using computer based linear programming.

Schleich and White (1997) applied linear programming technique to identify the least cost strategy for reaching politically specified phosphorus and total suspended solids reduction targets for the Fox-Wolf river basin in Northeast Wisconsin for determining the least cost management strategy.

Akamine (1997) used Linear programming for optimizing the fishing policy on discrete fishing equations using natural mortality rates, stock sizes or survival rates being control variables, giving fishing rates for the optimum fishing policy.

Jeyaraman (1997) described about the application of linear programming for optimization of income in integrated rice-fish-duck-vegetable farming system and for the optimal combination of different farming sub-systems for adoption, revealing the results of increased farm income, additionally generated employment and reduced farm business risk.

Yoon *et al.* (1997) used a least cost linear programming to optimize blending for surimi lots based on value, constraints and decision variables. They established a linear relationship between shear stress, shear strain and whiteness of surimi gels made with high and low grades of Alaska pollock and Pacific whiting before optimization.

Setboonsarng and Edwards (1998) used linear programming model to examine the economic viability of four fish production strategies in the context of rain fed farming systems in the northeastern region of Thailand. Also they used linear programming to determine the optimum farm product mix that maximizes net returns under each of the four production systems such as rice bran feeding system, pond fertilization using buffalo manure, fish production recommendations developed by the Asian Institute of Technology and an integrated duck/fish production system.

Quinn *et al.* (1998) carried out a case study as an application of linear programming theory, to determine optimal well placement and pump rates in ground water extraction systems. The objective of their study was optimization of groundwater containment by minimizing the rate of groundwater extraction while preventing discharge to the marsh across a user- specified boundary.

Forsberg (1999) integrated two size structured growth models in a multiperiod linear programming model for optimum harvesting of farmed Atlantic salmon for two management strategies with harvest operation restrictions. Allan and Rowland (1999) formulated one of two test diets using a least-cost linear feed formulation program and a range of Australian agricultural products based on digestibility coefficients to compare the performance and taste (consumer sensory evaluation) of silver perch (*Bidyanus bidyanus)* fed with meat meal diets and grown in earthen ponds to market size. They showed that there were no significant differences between the performances of silver perch fed with any of the diets.

Allan *et al.* (2000) showed that diet formulated using linear least-cost program does not significantly affect the body composition (nitrogen, fat, ash or energy) or sensory quality of Australian silver perch *(Bidyanus bidyanus*). They showed that there is no significant difference between the performances of silver perch fed with two test diets and least-cost diets.

Eguia *et al.* (2000) formulated four isocaloric diets with different protein levels by linear programming using amino acid profiles of two-day-old river catfish *Mystus nemurus* (Cuvier & Valenciennes) larvae during weaning to get better growth and survival.

3. MATERIAL AND METHOD

Feed formulations for juvenile of Tiger shrimp, juveniles of giant freshwater prawn, fry of Rohu, Catfish, Milkfish, Tilapia, Asian sea bass and Grouper were attempted in this study. For the first three species feed formulations with and without amino acid constraints were attempted. Among different fish feed ingredients available in the country, twenty-five ingredients were considered for feed formulation through linear programming. Nutritional requirements of these species in terms of sixteen nutrients namely crude protein, arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine, crude fibre, nitrogen free extract (NFE = soluble carbohydrate), lipid, digestible energy and calcium & phosphorous ratio were collected from literatures and used for the analysis. The feed ingredients and their nutritional compositions collected from publications and internet [Nakamura (1981), New (1987), Chou (1993), Nandeesha (1993), Pantha (1993), Bautista *et al.* (1994), George and Gopakumar (1995), Vander and Verdegem (1996), Cruz Philip (1997), Paulraj (1997), Ahamad *et al.* (1998), Chiou *et al.* (1998), Fagbenro *et al.* (2000), www.seaofindia.com, www.unu.edu and www.fao.org] are given in table-1. All data collected are expressed here only in percentage of dry weight (dw). Digestible energy (DE) of these ingredients for fish was calculated using the formula (New, 1987):

Plant origin (non legumes):

DE (kcal/kg) = [DW % of Protein × 3.8 + DW% of NFE × 3.0 + DW % of Lipid × 8.0] × 10

Plant origin (legumes):

DE (kcal/kg) = [DW % of Protein × 3.8 + DW% of NFE × 2.0 + DW % of Lipid × 8.0] × 10

Animal origin:

DE (kcal/kg) = [DW % of Protein × 4.25 + DW% of NFE × 3.0 + DW % of Lipid × 8.0] × 10.

The digestible energy of ingredients for fish calculated by this method was used for crustaceans also. The dry weight % of Calcium (Ca) was divided by dry weight % of Phosphorous (P) present in the ingredients to get the Ca/P ratio.

Table-1: Nutritional composition of different aquafeed ingredients (column 1 to 14, values are in % of dry matter, DE in kcal/kg of dry weight)

No	Ingredients	Protein	Arg	Hist	Ile	Leu	Lys	Met	Phe	Thre	Try	Val	NFE	Fibre	Lipid	DE	Ca/P
1	Rice polish	13.50	0.57	0.19	0.39	0.78	0.58	0.22	0.42	0.38	0.11	0.80	52.00	10.00	17.80	3497	0.03
2	Rice broken	13.30	0.96	0.25	0.53	0.90	0.44	0.25	0.56	0.41	0.17	0.76	72.70	5.90	4.70	3062	0.94
3	Rice bran	14.10	0.79	0.23	0.46	0.70	0.49	0.23	0.44	0.43	0.10	0.69	40.60	21.50	12.60	2762	0.12
4	Wheat bran	15.00	1.09	0.44	0.57	1.03	0.65	0.22	0.62	0.51	0.28	0.78	65.20	13.60	2.90	2758	0.07
5	Wheat flour	16.60	1.09	0.46	0.62	1.20	0.67	0.26	0.75	0.57	0.22	0.82	73.50	3.10	4.20	3172	0.15
6	Ground oil cake meal	46.70	4.55	0.95	1.76	2.70	1.77	0.42	2.04	1.16	0.48	1.88	28.00	14.40	8.10	2983	0.30
7	Sunflower oil cake meal	42.70	4.75	1.32	2.42	4.12	2.06	1.25	2.54	2.07	0.65	2.80	29.50	16.10	4.00	2827	0.23
8	Soybean meal	52.80	3.38	1.19	2.27	3.65	2.99	0.58	2.36	1.85	0.71	2.25	46.70	6.60	1.50	3060	0.19
9	Rapeseed cake meal	40.30	2.26	1.09	1.48	2.74	2.18	0.78	1.55	1.72	0.47	1.96	36.10	14.80	1.00	2694	0.70
10	Cottonseed cake meal	46.10	4.62	1.21	1.67	2.56	1.86	0.64	2.46	1.52	0.61	2.06	31.00	15.10	0.70	2738	0.13
11	Copra meal	23.40	2.65	0.41	0.91	1.59	0.66	0.35	0.95	0.73	0.22	1.14	44.20	15.70	10.00	3015	0.36
12	Sorghum meal	10.00	0.31	0.22	0.40	1.35	0.20	0.14	0.50	0.31	0.12	0.51	84.70	1.50	2.60	3129	0.42
13	Spirulina	55.30	2.73	0.55	3.90	5.20	3.00	0.91	3.25	3.00	0.91	4.22	29.20	2.30	1.10	3065	0.15
14	*Eichhornia* meal	20.20	1.43	0.51	1.20	2.14	1.47	0.42	1.29	1.17	0.19	1.41	48.90	18.90	2.40	2427	0.97
15	Mustard oil cake	33.70	1.89	0.88	1.55	2.26	1.45	0.57	1.31	1.48	0.44	1.72	38.10	6.80	10.20	3240	0.39
16	Maize meal	9.40	0.38	0.24	0.33	1.12	0.24	0.15	0.43	0.32	0.07	0.43	85.30	1.00	3.30	3180	0.08
17	Fish meal	55.60	3.11	1.28	2.56	4.23	4.34	1.67	2.22	2.39	0.67	3.00	8.10	3.00	12.00	3566	2.51
18	Shrimp meal	35.50	2.20	0.89	1.49	2.38	1.92	0.71	1.38	1.24	0.36	1.56	16.00	12.70	7.00	2549	7.50
19	Squid meal	76.40	5.73	1.68	3.21	5.88	6.00	2.14	2.60	3.13	0.76	3.29	2.10	4.40	5.50	3750	0.53
20	Clam meal	55.20	6.50	6.50	1.46	8.05	9.80	1.96	6.52	0.70	0.03	0.23	23.90	4.20	9.70	3839	0.74
21	Snail meal	40.81	2.20	0.75	2.89	2.29	1.11	0.76	1.63	1.52	0.48	2.22	22.90	1.58	1.77	2563	4.87
22	Blood meal	88.50	3.88	5.59	0.98	11.86	8.04	0.95	6.36	3.93	1.13	8.13	3.90	0.40	1.20	3974	1.00
23	Meat meal	54.40	3.60	1.02	1.75	3.19	3.23	0.70	1.81	1.64	0.34	2.25	28.00	7.40	4.80	3536	0.29
24	Poultry byproduct meal	59.90	4.03	1.08	2.54	4.28	3.10	1.13	1.97	2.08	0.50	3.06	5.40	2.10	17.10	4076	2.08
25	Hydrolysed feather meal	91.40	7.58	1.06	4.37	7.46	2.49	0.59	3.28	4.27	0.56	6.97	0.50	0.40	3.90	4212	0.82

The market prices of ingredients used in this analysis were collected from different places like local markets at Kochi (Kerala), Tuticorin (Tamil Nadu) market, Bhubaneswar (Orissa) market and MPEDA, and from publications namely Tacon (2000) and MPEDA (2001) and these are given in the table-2. Indian rupees forty eight per US $ was taken as the rate while converting the international market price of hydrolyzed feather meal into Indian market price.

Table-2: Different market prices of Ingredients [Rupees/kg dry weight]

No.	Ingredients	Kochi	Tuticorin	Bhubaneswar
1	Rice polish	8.00	15.00	15.00
2	Rice broken	12.00	10.00	6.50
3	Rice bran	3.10	5.00	3.00
4	Wheat bran	5.35	8.00	4.00
5	Wheat flour	11.50	10.00	14.00
6	Ground nut oil cake meal	12.00	13.00	10.50
7	Sunflower oil cake meal	5.70	27.50	5.00
8	Soybean meal	11.50	12.00	12.00
9	Rapeseed cake meal	7.00	17.50	8.00
10	Cottonseed cake meal	12.50	7.50	7.50
11	Copra meal	11.50	11.50	11.50
12	Sorghum meal	3.80	5.50	7.00
13	*Spirulina*	900.00	800.00	1200.00
14	*Eichhornia* meal	2.50	2.50	2.50
15	Mustard oil cake	12.00	12.00	3.50
16	Maize meal	10.00	10.00	12.00
17	Fish meal	32.59	55.00	15.00
18	Shrimp meal	25.71	45.00	30.00
19	Squid meal	56.69	55.00	56.69
20	Clam meal	59.27	75.00	59.27
21	Snail meal	112.50	50.00	112.50
22	Blood meal	18.24	50.00	18.24
23	Meat meal	8.50	60.00	9.55
24	Poultry byproduct meal	12.31	7.50	3.50
25	Hydrolyzed feather meal	9.65	9.65	9.65

Different nutritional requirements of above mentioned fish species and ingredient constraints in their feed were collected from different publications and tabulated in the table-3 for *Penaeus monodon* juveniles [Alava (1983), New (1987), Akiyama *et al.* (1992), Tacon (1993), Millamena (1996), Millamena *et al.* (1996), MPEDA (1996), Paulraj (1997), Millamena *et al.* (1998), Millamena *et al.* (1999) and Natarajan *et al.* (2001)]; table-4 for *Macrobrachium rosenbergii* juveniles [New (1987), Tacon (1993), Paulraj (1997), Paymon *et al.* (2000), Ruiquan *et al.* (2000a) and Ruiquan *et al.* (2000b)]; table-5 for Rohu (*Labeo rohita*) fry [Mazid *et al.* (1987), New (1987), Khan and Jafri (1993), Murthy and Varghese (1993), Murthy and Varghese (1995), Hussain and Shikha (1996), Murthy and Varghese (1996), Shivananda and Varghese (1996a), Shivananda and Varghese (1996b), Jain (1998), Mukhopadhyay and Ray (1999), and Anwar and Jafri (2001)]; table-6 for Catfish fry [New (1987), Giri (2001) and Pandian *et al.* (2001)]; table-7 for Milkfish (*Chanos chanos*) fry [New(1987) and Bautista *et al.* (1994)]; table-8 for Tilapia fry [New (1987), Bautista *et al.* (1994), Paulraj (1997) and Pandian *et al.* (2001)]; table-9 for Asian sea bass (*Lates calcarifer*) fry [New (1987) and Paulraj (1997)] and table-10 for Grouper fry [New (1987) and Chen (2001)]. All the requirements data [except for DE (kcal/kg dry weight) and Ca/P ratio] are in percentage of dry weight of total feed mixture. Requirements for protein, essential amino acids and digestible energy data are kept as minimum requirements level (De Silva and Anderson, 1995) and (Akiyama et al. 1992).

Table-3: Nutritional Requirements of *Penaeus monodon* juveniles		
Sl. No	Nutrients / Ingredients	Constraints (of total dry feed)
1	Protein	≥ 40%
2	Lipid	≥ 4% & ≤ 10%
3	NFE	≥ 10% & ≤ 30 %
4	Fibre	≤ 4%
5	Ca / P (Ratio)	≥ 1.0 & ≤ 1.5
6	Digestible Energy	≥ 2850 Kcal/Kg
7	Arg	≥ 1.85 %
8	Hist	≥ 0.8 %
9	Ile	≥ 1.01 %
10	Leu	≥1.7 %
11	Lys	≥ 2.08 %
12	Met	≥ 1.64 %
13	Phe	≥ 1.4 %
14	Thre	≥ 2.27 %
15	Try	≥ 0.2 %
16	Val	≥ 1.35%
17	Blood meal	≤ 7%
18	Shrimp meal	≤ 25%
19	Soybean meal	≤ 25%
20	Copra meal	≤ 15%
21	Cotton seed meal	≤ 20%
22	Hydrolyzed Feather meal	≤ 15%
23	Meat meal	≤ 20%
24	Rice bran	≤ 20%
25	Wheat bran	≤ 20%

Table-4: Nutritional Requirements of *Macrobrachium rosenbergii* juveniles		
Sl.No	Nutrients / Ingredient	Constraints (of total dry feed)
1	Protein	≥ 37.02%
2	Lipid	0.05
3	NFE	≥ 25% & ≤ 35 %
4	Crude fibre	≤ 4%
5	Ca / P (Ratio)	≥ 0.56 & ≤ 1.00
6	Digestible Energy	≥ 3200 Kcal/Kg
7	Arg	≥ 2.56 %
8	Hist	≥ 1.07 %
9	Ile	≥ 1.56 %
10	Leu	≥ 2.81 %
11	Lys	≥ 2.37 %
12	Met	≥ 0.52 %
13	Phe	≥ 3.59%
14	Thre	≥ 1.67 %
15	Try	≥ 0.52 %
16	Val	≥ 1.56 %
17	Shrimp meal	≤ 25%
18	Soybean meal	≤ 35%
19	Copra meal	≤ 20%
20	Cotton seed meal	≤ 25%
21	Hydrolyzed Feather meal	≤ 20%
22	Meat meal	≤ 25%
23	Rice bran	≤ 30%
24	Wheat bran	≤ 30%

Table-5: Nutritional Requirements of *Labeo rohita* fry		
Sl.No	Nutrients / Ingredient	Constraint (of total dry feed)
1	Protein	≥38 %
2	Lipid	≥5 %
3	NFE (carbohydrate)	≥41.5%
4	Ca / P (Ratio)	≥0.425 & ≤ 1.8
5	Digestible Energy	≥3100 Kcal/Kg
6	Arg	≥2.3 %
7	Hist	≥0.9 %
8	Ile	≥1.2 %
9	Leu	≥1.41 %
10	Lys	≥2.24 %
11	Met	≥1.00 %
12	Phe	≥1.6%
13	Thre	≥1.71 %
14	Try	≥0.22 %
15	Val	≥1.35 %
16	Copra meal	≤30%
17	Rice bran	≤30%
18	Wheat bran	≤30%
19	Eichhornia meal	≤30%

Table-6: Nutritional Requirements of Catfish fry		
Sl.No	Nutrients / Ingredient	Constraint (of total dry feed)
1	Protein	≥35%
2	Lipid	0.1
3	NFE (carbohydrate)	≥ 49%
4	Crude fibre	≤ 8 %
5	Digestible Energy	≥ 2700 Kcal/Kg
6	Arg	≥1.51 %
7	Hist	≥0.53 %
8	Ile	≥0.91 %
9	Leu	≥ 1.23 %
10	Lys	≥1.75 %
11	Met	≥0.81 %
12	Phe	≥1.75%
13	Thre	≥0.7 %
14	Try	≥0.18 %
15	Val	≥1.05%
16	Cotton seed meal	≤15 %

Table-7: Nutritional Requirements of Milkfish (*Chanos chanos*) fry		
Sl.No	Nutrients	Constraint (of total dry feed)
1	Protein	≥40%
2	Lipid	≥ 7 % & ≤10%
3	NFE	≥ 25%
4	Digestible Energy	≥2500 Kcal/Kg
5	Arg	≥2.08 %
6	Hist	≥0.8 %
7	Ile	≥1.6 %
8	Leu	≥2.04 %
9	Lys	≥1.6%
10	Met	≥0.68 %
11	Phe	≥1.28%
12	Thre	≥1.8 %
13	Try	≥0.24%
14	Val	≥1.44 %

Table-8: Nutritional Requirements of Tilapia fry		
Sl.No	Nutrients / Ingredient	Constraints (of total dry feed)
1	Protein	≥35%
2	Lipid	≥8 %
3	NFE	≥ 25%
4	Crude fibre	≤ 10 %
5	Digestible Energy	≥ 2500 Kcal/Kg
6	Arg	≥1.47 %
7	Hist	≥0.6 %
8	Ile	≥1.085 %
9	Leu	≥1.19 %
10	Lys	≥1.79 %
11	Met	≥0.95 %
12	Phe	≥1.3%
13	Thre	≥1.33 %
14	Try	≥0.35 %
15	Val	≥0.98 %
16	Copra meal	Should be nil in the feed
17	Fish meal	≥18%

Table-9: Nutritional Requirements of Asian sea bass (*Lates calcarifer*) fry		
Sl.No	Nutrients / Ingredient	Constraints (of total dry feed)
1	Protein	≥43 %
2	Lipid	=10.0%
3	NFE (carbohydrate)	≥ 20%
4	Ca / P (Ratio)	≥ 1.88 & ≤ 2.0
5	Digestible Energy	≥ 2700 Kcal/Kg
6	Arg	≥1.63 %
7	Lys	≥1.94 %
8	Met	≥1.01%
9	Try	≥0.22 %
10	Fish meal	20 to 40 %

Table-10: Nutritional Requirements of Grouper fry		
Sl.No	Nutrients / Ingredient	Constraints (of total dry feed)
1	Protein	≥47.8 %
2	Lipid	≤14 %
3	NFE	≤ 20%
4	Fibre	≤ 6%
5	Digestible Energy	≥3400 Kcal/Kg
6	Met	≥0.97%
7	Fish meal	20 to 40 %

All the constraints were made into linear equations/ inequalities forms. For example, protein requirement of Tiger shrimp juvenile is at least 40% of the total feed and the corresponding linear constraint is

$-0.135\ x_1-0.133\ x_2-0.141\ x_3-0.15\ x_4-0.166\ x_5-0.467\ x_6-0.427\ x_7-0.528\ x_8-0.403\ x_9-0.461\ x_{10}-0.234\ x_{11}-0.1\ x_{12}-0.553\ x_{13}-0.202\ x_{14}-0.337\ x_{15}-0.094\ x_{16}-0.556\ x_{17}-0.355\ x_{18}-0.764\ x_{19}-0.552\ x_{20}-0.408\ x_{21}-0.885\ x_{22}-0.544\ x_{23}-0.599\ x_{24}-0.914\ x_{25} \leq -0.4$

Where, x_1, x_2,..., x_{25} are the amounts of twenty-five feed ingredients which would be present in the final blend. All the inequality equations are expressed only with 'less than or equal to' sign at the right. Likewise, including protein and all other nutrients requirement, nineteen such inequality equations were made in case of *P. monodon* juveniles while one equality equation was obtained because the summation of ingredients (SI) to be selected by linear programming should be equal to 91.95% (i.e. 0.9195) as the remaining 8.05% [Cod liver oil (2.50%), soybean oil (1.22%), vitamin mix (2.00%), mineral mix. (0.28%), ethoxyquin (0.05%), and binder (2.00%); New (1987) and Bautista *et al.* (1994)] stands as fixed amount (FA) which, not to be selected by linear programming, is to be added to the formulation.

The equality constraints was accordingly taken as

$$\sum_{i=1}^{25} x_i = 0.9195$$

The upper boundaries (ub) fixed for different ingredients in case of tiger shrimp are given in the table-11 and lower boundaries (lb) of all ingredients are zero (0).

In case of *M. rosenbergii* juveniles SI was kept at 90.37% and FA at 9.63% [Soy lecithin (5.00%), Cod liver oil (1.00%), Mineral mix (0.28%), Cholesterol (0.25%), Vitamin C (0.50%), Inositol (0.40%), Attractive stimulant (0.20%) and Binder (2.00%); New (1987) and Tiwari (1999)]. Similarly for *L. rohita* fry SI was kept at 97.7% and FA at 2.3% [Vitamin mix (1.00%), Mineral mix (1.00%) and Table salt (0.30%); New (1987)]; for catfish fry SI at 92.00%, FA at 8.00% [Fish oil or Soybean oil (6.00%), Vit.C+ Mineral premix (1.60%) and Binder (0.40%); New (1987)]; for milkfish fry SI at 95.00%, FA at 5.00% [Coconut oil (1.00%), Tricalcium phosphate (2.00%) and Vit. mix commercial (2.00%); Sumagaysay *et al.* (1991)]; for tilapia fry SI at 90.67%, FA at 9.33% [Cod liver oil (1.00%), Vegetable oil (1.00%), Vit. +Mineral mixes (4.33%) and Starch (3.00%); Santiago *et al.* (1982)]; for *L. calcarifer* fry SI at 88.25%, FA at 11.75%[Cod liver oil (2.88%), Soybean oil (2.87%), Vit. Mix (4.00%) and Mineral mix (2.00%); Bautista *et al.* (1994)] and for grouper fry SI around 85.70%, FA around 14.30% [Cod liver oil (6.00%), Lecithin (4.00), Mineral mix (4.30) and Vit.B6 (0.00029%); Chen (2001)].

Like *P. monodon* juveniles, an equality constraint was found out for all other species with the exception of *M. rosenbergii* juveniles, catfish fry and *L. calcarifer* fry where two equality constraints were found out. Lower boundaries of all the ingredients for all the species are zero (0) except for fishmeal, which is twenty in case of *L. calcarifer* fry and grouper fry. Upper boundaries of ingredients can be up to SI level except for some ingredients specified for the species, and for copra meal, which is zero in case of tilapia fry.

Table-11: Upper boundaries of ingredients for *P. monodon* juveniles feed		
No.	Ingredients	ub
1	Rice polish	0.9195
2	Rice broken	0.9195
3	Rice bran	0.2000
4	Wheat bran	0.2000
5	Wheat flour	0.9195
6	Ground nut oil cake meal	0.9195
7	Sunflower oil cake meal	0.9195
8	Soybean meal	0.2500
9	Rapeseed cake meal	0.9195
10	Cottonseed cake meal	0.2000
11	Copra meal	0.1500
12	Sorghum meal	0.9195
13	Spirulina	0.9195
14	Eichhornia meal	0.9195
15	Mustard oil cake	0.9195
16	Maize meal	0.9195
17	Fish meal	0.9195
18	Shrimp meal	0.2500
19	Squid meal	0.9195
20	Clam meal	0.9195
21	Snail meal	0.9195
22	Blood meal	0.0700
23	Meat meal	0.2000
24	Poultry byproduct meal	0.9195
25	Hydrolyzed feather meal	0.1500

For all the calculations the computer software used is MATLAB. MATLAB, a software product of Math Works Inc., USA, stands for matrix laboratory, which is a high performance language for technical computing and it represents a state of the art in software for matrix computation. An application-specific solution known as toolbox for optimization is available in MATLAB for linear programming (LP) applications. This is a comprehensive collection of MATLAB functions to extent the MATLAB environment to solve linear programming problems. The matlab function for solving a LP problem is "*linprog*" and the type of linear programming problem attended here is

$\min_{x} f'x$ such that

$$
\begin{aligned}
A.x &\leq b \\
Aeq.x &= beq \\
lb \leq x &\leq ub
\end{aligned}
$$

where, f, x, b, beq, lb, ub, are vectors, and A and Aeq are matrices.

The syntax of the function "linprog" is

[x, fval, exitflag, output, lambda] = linprog(f, A, b, Aeq, beq, lb, ub);

Here, the input arguments are

f	=	*the vector with coefficients of the objective function as elements*
A	=	matrix with coefficients of the inequality constraint equations that will be of order of $k \times n$.
b	=	right hand side vector for the inequality constraints.
Aeq	=	matrix with coefficients for the equality constraints equations.
beq	=	right hand side vector for the equality constraints.
lb	=	lower bound for the solution vector.
ub	=	upper bound for the solution vector.
x	=	the solution vector that satisfies the constraints and result in minimum possible value for the objective function.
fval	=	value of the objective function for the solution vector x.
exitflag	=	the condition of termination or exit of the optimization algorithm. If it holds a value more than zero, the function has converged to a feasible solution. If it is zero(0), the maximum allowed iterations are exceeded before convergence and If it is less than zero a feasible solution does not exist.

lambda = the output lambda is a structure containing the Lagrange multipliers at the solution x

output = it is a structure containing information about the optimization with element number of iterations taken, algorithm used, etc.

This optimization is using a Linear Interior Point Solver based on Mehrotra's predictor-corrector algorithm, which is a variation of the well-known simplex method. Simplex search method does not use numerical or analytic gradients. Gradient methods use information about slope of the function to control direction of search for the solution. If n is the length of vector x, a simplex in n dimensional space is characterized by the (n+1) distinct vectors that are its vertices. In two-dimensional space a simplex is a triangle, in three-dimensional space it is a pyramid. At each step of the search a new point in or near the current simplex is generated. The function value at the new point is compared with the function value at the vertices of the simplex and one of the vertices is replaced by the new point to form a new simplex. This process is continued until the diameter of the simplex is less than the specified tolerance.

The inequality constraint matrix 'A' and the corresponding right hand vector ' b' generated with nutrient requirements of *P. monodon* juveniles are given in Table-12. Since all inequality constraints are needed only with ' less than or equal to ' sign where ever the requirements are in a range two constraints are formed to satisfy this condition. Likewise matrix 'A' and Vector 'b''were generated for all other species based on their nutritional requirements. Equality constraints matrix Aeq and corresponding right hand vector beq were also generated in a similar way.

Table-12: The inequality constraint matrix 'A' and the corresponding Vector '*b*' generated with nutrient requirements of *P. monodon* juveniles

Ingredient	Protein	Arg	Hist	Ile	Leu	Lys	Met	Phe	Thre	Try	Val	NFE-1	NFE-2	Fibre	Lipid-1	Lipid-2	DE	Ca/P-1	Ca/P-2
1	-0.135	-0.006	-0.002	-0.004	-0.008	-0.006	-0.002	-0.004	-0.004	-0.001	-0.008	-0.520	0.520	0.100	-0.178	0.178	-3497	-0.030	0.030
2	-0.133	-0.010	-0.003	-0.005	-0.009	-0.004	-0.003	-0.006	-0.004	-0.002	-0.008	-0.727	0.727	0.059	-0.047	0.047	-3062	-0.940	0.940
3	-0.141	-0.008	-0.002	-0.005	-0.007	-0.005	-0.002	-0.004	-0.004	-0.001	-0.007	-0.406	0.406	0.215	-0.126	0.126	-2762	-0.120	0.120
4	-0.150	-0.011	-0.004	-0.006	-0.010	-0.007	-0.002	-0.006	-0.005	-0.003	-0.008	-0.652	0.652	0.136	-0.029	0.029	-2758	-0.070	0.070
5	-0.166	-0.011	-0.005	-0.006	-0.012	-0.007	-0.003	-0.008	-0.006	-0.002	-0.008	-0.735	0.735	0.031	-0.042	0.042	-3172	-0.150	0.150
6	-0.467	-0.046	-0.010	-0.018	-0.027	-0.018	-0.004	-0.020	-0.012	-0.005	-0.019	-0.280	0.280	0.144	-0.081	0.081	-2983	-0.300	0.300
7	-0.427	-0.048	-0.013	-0.024	-0.041	-0.021	-0.013	-0.025	-0.021	-0.007	-0.028	-0.295	0.295	0.161	-0.040	0.040	-2827	-0.230	0.230
8	-0.528	-0.034	-0.012	-0.023	-0.037	-0.030	-0.006	-0.024	-0.019	-0.007	-0.023	-0.467	0.467	0.066	-0.015	0.015	-3060	-0.190	0.190
9	-0.403	-0.023	-0.011	-0.015	-0.027	-0.022	-0.008	-0.016	-0.017	-0.005	-0.020	-0.361	0.361	0.148	-0.010	0.010	-2694	-0.700	0.700
10	-0.461	-0.046	-0.012	-0.017	-0.026	-0.019	-0.006	-0.025	-0.015	-0.006	-0.021	-0.310	0.310	0.151	-0.007	0.007	-2738	-0.130	0.130
11	-0.234	-0.027	-0.004	-0.009	-0.016	-0.007	-0.004	-0.010	-0.007	-0.002	-0.011	-0.442	0.442	0.157	-0.100	0.100	-3015	-0.360	0.360
12	-0.100	-0.003	-0.002	-0.004	-0.014	-0.002	-0.001	-0.005	-0.003	-0.001	-0.005	-0.847	0.847	0.015	-0.026	0.026	-3129	-0.420	0.420
13	-0.553	-0.027	-0.006	-0.039	-0.052	-0.030	-0.009	-0.033	-0.030	-0.009	-0.042	-0.292	0.292	0.023	-0.011	0.011	-3065	-0.150	0.150
14	-0.202	-0.014	-0.005	-0.012	-0.021	-0.015	-0.004	-0.013	-0.012	-0.002	-0.014	-0.489	0.489	0.189	-0.024	0.024	-2427	-0.970	0.970
15	-0.337	-0.019	-0.009	-0.016	-0.023	-0.015	-0.006	-0.013	-0.015	-0.004	-0.017	-0.381	0.381	0.068	-0.102	0.102	-3240	-0.390	0.390
16	-0.094	-0.004	-0.002	-0.003	-0.011	-0.002	-0.002	-0.004	-0.003	-0.001	-0.004	-0.853	0.853	0.010	-0.033	0.033	-3180	-0.080	0.080
17	-0.556	-0.031	-0.013	-0.026	-0.042	-0.043	-0.017	-0.022	-0.024	-0.007	-0.030	-0.081	0.081	0.030	-0.120	0.120	-3566	-2.510	2.510
18	-0.355	-0.022	-0.009	-0.015	-0.024	-0.019	-0.007	-0.014	-0.012	-0.004	-0.016	-0.160	0.160	0.127	-0.070	0.070	-2549	-7.500	7.500
19	-0.764	-0.057	-0.017	-0.032	-0.059	-0.060	-0.021	-0.026	-0.031	-0.008	-0.033	-0.021	0.021	0.044	-0.055	0.055	-3750	-0.530	0.530
20	-0.552	-0.065	-0.065	-0.015	-0.081	-0.098	-0.020	-0.065	-0.007	0.000	-0.002	-0.239	0.239	0.042	-0.097	0.097	-3839	-0.740	0.740
21	-0.408	-0.022	-0.008	-0.029	-0.023	-0.011	-0.008	-0.016	-0.015	-0.005	-0.022	-0.229	0.229	0.016	-0.018	0.018	-2563	-4.870	4.870
22	-0.885	-0.039	-0.056	-0.010	-0.119	-0.080	-0.010	-0.064	-0.039	-0.011	-0.081	-0.039	0.039	0.004	-0.012	0.012	-3974	-1.000	1.000
23	-0.544	-0.036	-0.010	-0.018	-0.032	-0.032	-0.007	-0.018	-0.016	-0.003	-0.023	-0.280	0.280	0.074	-0.048	0.048	-3536	-0.290	0.290
24	-0.599	-0.040	-0.011	-0.025	-0.043	-0.031	-0.011	-0.020	-0.021	-0.005	-0.031	-0.054	0.054	0.021	-0.171	0.171	-4076	-2.080	2.080
25	-0.914	-0.076	-0.011	-0.044	-0.075	-0.025	-0.006	-0.033	-0.043	-0.006	-0.070	-0.005	0.005	0.004	-0.039	0.039	-4212	-0.820	0.820
b'	-0.400	-0.019	-0.008	-0.010	-0.017	-0.021	-0.016	-0.014	-0.023	-0.002	-0.014	-0.100	0.300	0.040	-0.040	0.100	-2850	-1.000	1.500

4. RESULTS

To arrive at optimum combination of feed formulation for all the species considered, three sets of costs were taken for optimization of feed ingredients, namely local market prices at Kochi, Tuticorin and Bhubaneswar (Table-2). The nutrient and ingredient constraints along with their upper and lower boundaries were kept same for all the three sets of costs. Feed without aminoacids constraints was also formulated for all the three sets of market prices in the case of juveniles of *Penaeus monodon*, juveniles of *Macrobrachium rosenbergii* and fry of *Labeo rohita*.

4.1 Feed formulation for juveniles of *Penaeus monodon*

For all the three sets of market price the nutrient and ingredient constraints were formulated based on the requirements as given in Table-3. With the market prices at Kochi taken as the cost for the twenty-five feed ingredients, optimization through linear programming using the toolbox of MATLAB, took 16 iterations for convergence. The optimum solution yielded a feed formulation with only five feed ingredients. These ingredients and their combination in percentage are Sunflower oil cake meal (5.65%), Sorghum meal (3.28%), Fish meal (42.91%), Squid meal (34.43%) and Clam meal (5.69%). The Kochi market prices of these ingredients in Rupees per kg dry weight are 5.70, 3.80, 32.59, 56.69 and 59.27 respectively. The total cost of these selected ingredients combination works out to Rs. 37.32. When ten essential amino acids constraints were removed for relaxing the constraints, it took 11 iterations to find an optimum solution for the corresponding linear programming problem with market prices at Kochi. Out of twenty-five only four ingredients were selected namely Sorghum meal (24.43%), *Eichhornia* meal (14.71%), Poultry byproduct meal (37.81%) and Hydrolyzed feather meal (15.00%). The market prices (Rs./kg) of these ingredients are 3.80, 2.50,12.31 and 9.65 respectively.

Total cost of these selected ingredients combination works out to Rs. 7.40 only.

Table-13: Proportion of ingredients selected as the linear programming solution for different market prices for *Penaeus monodon* juveniles

No.	Ingredients	With all constraints			Without aminoacid constraints		
		Kochi	Tuticorin	Bhubaneswar	Kochi	Tuticorin	Bhubaneswar
7	Sunflower oil cake meal	0.057	0.000	0.057	0.000	0.000	0.000
12	Sorghum meal	0.033	0.084	0.033	0.244	0.220	0.136
14	*Eichhornia* meal	0.000	0.000	0.000	0.147	0.135	0.042
15	Mustard oil cake	0.000	0.000	0.000	0.000	0.000	0.331
17	Fish meal	0.429	0.032	0.429	0.000	0.000	0.000
18	Shrimp meal	0.000	0.050	0.000	0.000	0.000	0.000
19	Squid meal	0.344	0.681	0.344	0.000	0.000	0.000
20	Clam meal	0.057	0.000	0.057	0.000	0.000	0.000
24	Poultry byproduct meal	0.000	0.073	0.000	0.378	0.523	0.346
25	Hydrolyzed feather meal	0.000	0.000	0.000	0.150	0.041	0.065

Table-14 shows details of nutrient contributions of the ingredients selected for Kochi market price to the total nutrients levels in 91.95% of the feed formulated by linear programming for *P. monodon*. The different nutrient levels in the selected ingredients combination are Protein (56.04%), Arginine (3.96%), Histidine (1.58%), Isoleucine (2.44%), Leucine (4.57%), Lysine (4.61%), Methionine (1.64%), Phenylalanine (2.38%), Threonine (2.27%), Tryptophan (0.59%), Valine (2.61%), NFE (10.00%), Fibre (4%), Lipid (7.91%), DE (3302.09 Kcal/Kg) and Ca/P ratio (1.33%). The Formula of dry pellet feed for juveniles of *Penaeus monodon* at Kochi market price is tabulated in Table-15 with all constraints with and without aminoacids.

Using Tuticorin market price, convergence for the optimum linear programming solution was arrived at after 17 iterations and the selected ingredients are Sorghum meal (8.41%), Fish meal (3.23%), Shrimp meal (4.95%), Squid meal (68.07%) and Poultry byproduct meal (7.28%) with Rs. 42.46 as the total cost of the ingredients. Without amino acid constraints the iterations necessary were 10 and selected ingredients are Sorghum meal (22.04%), Table-14: Percentage contributions of selected ingredients (in Kochi market price with all constraints) towards different nutrient requirements for *P. monodon* juveniles

Ingredients	Sunflower oil cake meal	Sorghum meal	Fish meal	Squid meal	Clam meal	Total
Proportion	0.0565	0.0328	0.4291	0.3443	0.0569	0.9196
Protein	2.41	0.33	23.86	26.30	3.14	56.04
Arg	0.27	0.01	1.33	1.97	0.37	3.96
Hist	0.07	0.01	0.55	0.58	0.37	1.58
Ile	0.14	0.01	1.10	1.11	0.08	2.44
Leu	0.23	0.04	1.82	2.02	0.46	4.57
Lys	0.12	0.01	1.86	2.07	0.56	4.61
Met	0.07	0.00	0.72	0.74	0.11	1.64
Phe	0.14	0.02	0.95	0.90	0.37	2.38
Thre	0.12	0.01	1.03	1.08	0.04	2.27
Try	0.04	0.00	0.29	0.26	0.00	0.59
Val	0.16	0.02	1.29	1.13	0.01	2.61
NFE	1.67	2.78	3.48	0.72	1.36	10.00
Fibre	0.91	0.05	1.29	1.51	0.24	4.00
Lipid	0.23	0.09	5.15	1.89	0.55	7.91
DE	159.73	102.63	1530.17	1291.13	218.44	3302.09
Ca/P	0.01	0.01	1.08	0.18	0.04	1.33

Table-15: Dry pellet feed formula (%) and nutrients in feed for juveniles of *Penaeus monodon* at Kochi market price

Formula	Aminoacid constraints		Nutrients in feed	Aminoacid constraints	
Ingredients	With	Without		With	Without
Sunflower oil cake meal	5.65	0.00	Protein	56.04	41.77
Sorghum meal	3.28	24.43	Arg	3.96	2.95
Fish meal	42.91	0.00	Hist	1.58	0.70
Squid meal	34.43	0.00	Ile	2.44	1.89
Clam meal	5.69	0.00	Leu	4.57	3.38
Eichhornia meal	0.00	14.71	Lys	4.61	1.81
Poultry byproduct meal	0.00	37.81	Met	1.64	0.61
Hydrolyzed feather meal	0.00	15.00	Phe	2.38	1.55
Cod liver oil	2.50	2.50	Thre	2.27	1.67
Soybean oil	1.22	1.22	Try	0.59	0.33
Vitamin mix.	2.00	2.00	Val	2.61	2.53
Mineral mix.	0.28	0.28	NFE	10.00	30.00
Ethoxyquin	0.05	0.05	Fibre	4.00	4.00
Binder	2.00	2.00	Lipid	7.91	8.04
			DE	3302.09	3294.36
Value of objective function	37.32	7.40	Ca/P	1.33	1.15

Eichhornia meal (13.52%), Poultry byproduct meal (52.30%) and Hydrolyzed feather meal (4.09%) with the total cost Rs. 5.87. The Formulae of pellet feed for juveniles of *Penaeus monodon* for Tuticorin market price with all constraints and without aminoacids constraints are tabulated in Table-16 along with different nutrient levels met by the proposed mix.

Table-16: The Formula (%) and nutrients in dry pellet feed for juveniles of *Penaeus monodon* at Tuticorin market price

Formula	Aminoacid constraints		Nutrients in feed	Aminoacid constraints	
Ingredients	With	Without		With	Without
Sorghum meal	8.41	22.04	Protein	60.76	40.00
Eichhornia meal	0.00	13.52	Arg	4.43	2.68
Fish meal	3.23	0.00	Hist	1.33	0.73
Shrimp meal	4.95	0.00	Ile	2.56	1.76
Squid meal	68.07	52.30	Leu	4.68	3.13
Poultry byproduct meal	7.28	0.00	Lys	4.56	1.97
Hydrolyzed feather meal	0.00	4.09	Met	1.64	0.70
Cod liver oil	2.50	2.50	Phe	2.10	1.45
Soybean oil	1.22	1.22	Thre	2.45	1.49
Vitamin mix.	2.00	2.00	Try	0.60	0.34
Mineral mix.	0.28	0.28	Val	2.68	2.19
Ethoxyquin	0.05	0.05	NFE	10.00	28.12
Binder	2.00	2.00	Fibre	4.00	4.00
			Lipid	5.94	10.00
			DE	3353.86	3321.78
Value of objective function	42.46	5.87	Ca/P	1.00	1.35

Using Bhubaneswar market price of the ingredients and all the nutritional constraints, linear programming optimization took 17 iterations for convergence. The selected ingredients are same as in the case with Kochi market price but with a different total cost of Rs. 29.84 for the ingredients combination. Without amino acid constraints the optimization took 13 iterations and the selected ingredients are Sorghum meal (13.59%), *Eichhornia* meal (4.20%), Mustard oil cake (33.07%), Poultry byproduct meal (34.62%) and Hydrolyzed feather meal (6.46%) with Rs. 4.05 as the total cost. The Formulae of pellet feed along with different nutrient levels in the proposed ingredients combination for juveniles of *Penaeus monodon* at Bhubaneswar market price are tabulated in the Table-17.

Table-17: The Formula (%) and nutrients in dry feed pellet for juveniles of *Penaeus monodon* at Bhubaneswar market price

Formula	Aminoacid constraints		Nutrients in feed	Aminoacid constraints	
Ingredients	*With*	*Without*		*With*	*Without*
Sunflower oil cake meal	5.65	0.00	Protein	56.04	39.99
Sorghum meal	3.28	13.59	Arg	3.96	2.61
Eichhornia meal	0.00	4.20	Hist	1.58	0.78
Mustard oil cake	0.00	33.07	Ile	2.44	1.78
Fish meal	42.91	0.00	Leu	4.57	2.98
Squid meal	34.43	0.00	Lys	4.61	1.80
Clam meal	5.69	0.00	Met	1.64	0.65
Poultry byproduct meal	0.00	34.62	Phe	2.38	1.45
Hydrolyzed feather meal	0.00	6.46	Thre	2.27	1.58
Cod liver oil	2.50	2.50	Try	0.59	0.38
Soybean oil	1.22	1.22	Val	2.61	2.21
Vitamin mix.	2.00	2.00	NFE	10.00	28.07
Mineral mix.	0.28	0.28	Fibre	4.00	4.00
Ethoxyquin	0.05	0.05	Lipid	7.91	10.00
Binder	2.00	2.00	DE	3302.09	3281.84
Value of objective function	29.84	4.05	Ca/P	1.33	1.00

4.2 Feed formulation for *Macrobrachium rosenbergii* juveniles

For all the three market prices sets, the nutrient and ingredient constraints were kept same as per the nutrients requirements given in the Table-4. With Kochi market price as the cost for the twenty-five feed ingredients, optimization through linear programming took 13 iterations for convergence. Among the twenty-five ingredients the optimum solution yielded a feed formulation with only eight ingredients. These are Rice polish (8.45%), Sunflower oil cake meal (3.76%), Soybean meal (23.48%), Sorghum meal (3.74%), Clam meal (17.85%), Blood meal (22.21%), Poultry byproduct meal (3.58%) and Hydrolyzed feather meal (7.29%) with a total cost of Rs.19.51. When the ten amino acids constraints were removed from the constraints, optimization attempted with market price at Kochi took 12 iterations for convergence.

Table-18: The Formula (%) and nutrients of feed (dry pellet) for juveniles of *Macrobrachium rosenbergii* at Kochi market price

Formula	Aminoacid constraints		Nutrients In feed	Aminoacid constraints	
Ingredients	With	Without		With	Without
Rice polish	8.45	0.00	Protein	53.83	41.61
Rice bran	0.00	3.84	Arg	3.75	2.96
Sunflower oil cake meal	3.76	0.00	Hist	2.87	0.66
Soybean meal	23.48	0.00	Ile	1.56	1.73
Sorghum meal	3.74	28.72	Leu	5.90	3.19
Eichhornia meal	0.00	3.55	Lys	4.66	1.72
Clam meal	17.85	0.00	Met	0.85	0.47
Blood meal	22.21	0.00	Phe	3.59	1.50
Meat meal	0.00	24.02	Thre	1.94	1.61
Poultry byproduct meal	3.58	10.24	Try	0.52	0.29
Hydrolyzed feather meal	7.29	20.00	Val	3.18	2.47
Soy lecithin	5.00	5.00	NFE	25.00	35.00
Cod liver oil	1.00	1.00	Fibre	4.00	4.00
Mineral mix.	0.28	0.28	Lipid	5.00	5.00
Cholesterol	0.25	0.25	DE	3258.17	3200.00
Vit.C	0.50	0.50	Ca/P	0.56	0.61
Inositol	0.40	0.40			
Attractive stimulant	0.20	0.20			
Binder	2.00	2.00			
Value of objective function	19.51	6.53			

The six ingredients selected by linear programming were Rice bran (3.84%), Sorghum meal (28.72%), *Eichhornia* meal (3.55%), Meat meal (24.02%), Poultry byproduct meal (10.24%) and Hydrolyzed feather meal (20.00%) with Rs. 6.53 as the total cost of ingredients. Formula and different nutrients levels in dry pellet for *Macrobrachium rosenbergii* juveniles for Kochi market price, satisfying all nutrients requirements with and without aminoacids are given in Table-18.

Solution to the linear programming problem set with all the nutrient and ingredient constraints and Tuticorin market price could be achieved in 14 iterations. It consisted of only five ingredients out of the 25 and these are Soybean meal (35.00%), Sorghum meal (3.17%), Clam meal (18.66%), Blood meal (19.83%), and Poultry byproduct meal (13.71%). According to this combination of ingredients the total cost is Rs. 29.32. Without amino acid constraints and Tuticorin market price, solution to the linear programming problem could be achieved in 11 iterations and selected ingredients according to this are Soybean meal (25.81%), Cottonseed cake meal (0.42%), Sorghum meal (25.64%), Poultry byproduct meal (18.50%) and Hydrolyzed feather meal (20.00%) with Rs.7.86 as the total cost for the ingredients. Feed Formula (%) and nutrients levels of feed (pellet) for juveniles of *Macrobrachium rosenbergii* at Tuticorin market price are given in Table-19.

Table-19: Feed Formula (%) and different nutrient levels of feed (pellet) for juveniles of *Macrobrachium rosenbergii* at Tuticorin market price

Formula	Aminoacid constraints		Nutrients In feed	Aminoacid constraints	
Ingredients	With	Without		With	Without
Soybean meal	35.00	25.81	Protein	54.86	45.75
Cottonseed cake meal	0.00	0.42	Arg	3.73	3.23
Sorghum meal	3.17	25.64	Hist	2.89	0.78
Clam meal	18.66	0.00	Ile	1.62	2.04
Blood meal	19.83	0.00	Leu	5.76	3.58
Poultry byproduct meal	13.71	18.50	Lys	4.90	1.90
Hydrolyzed feather meal	0.00	20.00	Met	0.92	0.52
Soy lecithin	5.00	5.00	Phe	3.59	1.77
Cod liver oil	1.00	1.00	Thre	1.85	1.80
Mineral mix.	0.28	0.28	Try	0.55	0.42
Cholesterol	0.25	0.25	Val	2.88	2.68
Vit.C	0.50	0.50	NFE	25.00	35.00
Inositol	0.40	0.40	Fibre	3.51	2.62
Attractive stimulant	0.20	0.20	Lipid	5.00	5.00
Binder	2.00	2.00	DE	3233.41	3200.02
Value of objective function	29.32	7.86	Ca/P	0.70	0.71

The optimum ingredient combination sought through linear programming with all *nutrient and ingredient constraints and* Bhubaneswar market price resulted in a feed combination with 6 ingredients after 14 iterations for convergence. These are Sunflower oil cake meal (6.91%), Soybean meal (25.33%), Sorghum meal (6.16%), Clam meal (18.49%), Blood meal (20.97%), and Poultry byproduct meal (12.50%). Cost of this combination of ingredients is Rs.19.04. Without amino acid constraints *and Bhubaneswar market price as the cost of* ingredients the optimum feed combination yielded after 12 iterations are Wheat bran (10.25%), Sorghum meal (24.61%), *Eichhornia* meal (2.00%), Meat meal (20.29%), Poultry byproduct meal (13.22%), and Hydrolyzed feather meal (20.00%) with only Rs. 6.51 as the total cost for the ingredients. The Feed Formula (%) and different nutrients levels *of pellet for juveniles of Macrobrachium rosenbergii* at Bhubaneswar market price are given in Table-20.

Table-20: Feed Formula (%) and nutrients of feed (pellet) for juveniles of *Macrobrachium rosenbergii* at Bhubaneswar market price

Formula	Aminoacid constraints		Nutrients In feed	Aminoacid constraints	
Ingredients	With	Without		With	Without
Wheat bran	0.00	10.25	Protein	53.19	41.64
Sunflower oil cake meal	6.91	0.00	Arg	3.72	3.00
Soybean meal	25.33	0.00	Hist	2.92	0.67
Sorghum meal	6.16	24.61	Ile	1.56	1.75
Eichhornia meal	0.00	2.00	Leu	5.80	3.19
Clam meal	18.49	0.00	Lys	4.80	1.71
Blood meal	20.97	0.00	Met	0.94	0.47
Meat meal	0.00	20.29	Phe	3.59	1.50
Poultry byproduct meal	12.50	13.22	Thre	1.84	1.61
Hydrolyzed feather meal	0.00	20.00	Try	0.54	0.31
Soy lecithin	5.00	5.00	Val	2.92	2.49
Cod liver oil	1.00	1.00	NFE	25.00	35.00
Mineral mix.	0.28	0.28	Fibre	4.00	4.00
Cholesterol	0.25	0.25	Lipid	5.00	5.00
Vit.C	0.50	0.50	DE	3215.87	3199.98
Inositol	0.40	0.40	Ca/P	0.70	0.63
Attractive stimulant	0.20	0.20			
Binder	2.00	2.00			
Value *of objective function*	19.04	6.51			

4.3 Feed formulation for fry of *Labeo rohita*

For arriving at a feed formulation for fry of *L. rohita* with cost set as the market price of the ingredients at Kochi and considering all the ingredient and nutrient constraints with and without aminoacids, optimum solution though linear programming was carried out. Convergence for reaching at optimum solution was achieved after 19 iterations for the case with all constraints and after 12 iterations for that without aminoacids constraints. The ingredients and their percentage in the optimum combination are Sunflower oil cake meal (6.86%), Maize meal (44.30%), Fish meal (12.74%), Squid meal (27.85%), Blood meal (1.08%), and Hydrolyzed feather meal (4.85%) with Rs. 25.43 as total cost when all constraints were considered, and Rice bran (20.77%), Sorghum meal (30.23%), *Eichhornia* meal (14.94%) and Hydrolyzed feather meal (31.76%) with Rs. 5.23 only as total cost when all without aminoacids constraints were considered.

Table-21: The Formula (%) and nutrients of dry feed for fry of *Labeo rohita* at Kochi market price

Formula	Aminoacid constraints		Nutrients In feed	Aminoacid constraints	
Ingredients	With	Without		With	Without
Rice bran	0.00	20.77	Protein	40.84	37.98
Sunflower oil cake meal	6.86	0.00	Arg	2.90	2.88
Sorghum meal	0.00	30.23	Hist	0.94	0.53
Eichhornia meal	0.00	14.94	Ile	1.75	1.78
Maize meal	44.30	0.00	Leu	3.45	3.24
Fish meal	12.74	0.00	Lys	2.68	1.17
Squid meal	27.85	0.00	Met	1.00	0.34
Blood meal	1.08	0.00	Phe	1.60	1.48
Hydrolyzed feather meal	4.85	31.76	Thre	1.71	1.71
Vit.mix.	1.00	1.00	Try	0.41	0.26
Mineral mix.	1.00	1.00	Val	2.11	2.72
Table salt	0.30	0.30	NFE	41.49	41.50
			Fibre	3.18	7.87
			Lipid	5.00	5.00
			DE	3348.56	3219.05
Value of objective function	25.43	5.23	Ca/P	0.57	0.56

The Formula (%) and nutrients of dry feed for fry of *Labeo rohita* at Kochi market price are given in Table-21.

With Tuticorin market price as the cost and considering all the ingredient and nutrient constraints, the linear programming optimization was reached in 16 iterations and the selected ingredients are Sorghum meal (3.98%), Maize meal (43.16%), Squid meal (37.49%), Blood meal (2.86%), Poultry byproduct meal (7.41%), and Hydrolyzed feather meal (2.80%). Total cost of these ingredients works out to Rs. 27.41. Without aminoacid constraints and same cost for the ingredients, linear programming optimization was achieved after 12 iterations and the selected ingredients are *Eichhornia* meal (30.00%), Sorghum meal (30.52%), Poultry byproduct meal (16.17%), and Hydrolyzed feather meal (21.01%) with Rs. 5.67 as the total cost. The Formula (%) and nutrients of dry feed for fry of *Labeo rohita* at Tuticorin market price are given in Table-22.

Table-22: The Formula (%) and nutrients of dry feed for fry of *Labeo rohita* at Tuticorin market price

Formula	Aminoacid constraints		Nutrients In feed	Aminoacid constraints	
Ingredients	With	Without		With	Without
Eichhornia meal	0.00	30.00	Protein	42.63	38.00
Sorghum meal	3.98	30.52	Arg	2.95	2.77
Maize meal	43.16	0.00	Hist	1.01	0.62
Squid meal	37.49	0.00	Ile	1.70	1.81
Blood meal	2.86	0.00	Leu	3.61	3.31
Poultry byproduct meal	7.41	16.17	Lys	2.89	1.53
Hydrolyzed feather meal	2.80	21.01	Met	1.00	0.48
Vit.mix.	1.00	1.00	Phe	1.60	1.55
Mineral mix.	1.00	1.00	Thre	1.71	1.68
Table salt	0.30	0.30	Try	0.40	0.29
			Val	2.09	2.54
			NFE	41.50	41.50
			Fibre	2.32	6.55
			Lipid	5.00	5.10
			DE	3436.52	3227.10
Value of objective function	27.41	5.67	Ca/P	0.46	0.93

With all the constraints and market price at Bhubaneswar as the cost, the optimum linear programming solution obtained after 17 iterations consists of the ingredients same as that obtained with Kochi market price as cost but the total cost of the ingredients is Rs. 24.03. Retaining the same cost for the ingredients but without aminoacid constraints the optimum linear programming solution was obtained after 14 iterations and the selected ingredients are Wheat bran (30.00%), Sorghum meal (9.60%), *Eichhornia* meal (5.95%), Mustard oil cake (28.30%), and Hydrolyzed feather meal (23.85%). Total cost of these ingredients is Rs. 5.31 only. The Formula (%) and nutrients of dry feed for fry of *Labeo rohita* at Bhubaneswar market price are given in Table-23.

Table-23: The Formula (%) and nutrients of dry feed for fry of *Labeo rohita* at Bhubaneswar market price

Formula	Aminoacid constraints		Nutrients In feed	Aminoacid constraints	
Ingredients	With	Without		With	Without
Wheat bran	0.00	30.00	Protein	40.84	38.00
Sorghum meal	0.00	9.60	Arg	2.90	2.78
Eichhornia meal	0.00	5.95	Hist	0.94	0.69
Mustard oil cake	0.00	28.30	Ile	1.75	1.76
Sunflower oil cake meal	6.86	0.00	Leu	3.45	2.98
Maize meal	44.30	0.00	Lys	2.68	1.31
Fish meal	12.74	0.00	Met	1.00	0.41
Squid meal	27.85	0.00	Phe	1.60	1.46
Blood meal	1.08	0.00	Thre	1.71	1.69
Hydrolyzed feather meal	4.85	23.85	Try	0.41	0.36
Vit.mix.	1.00	1.00	Val	2.11	2.52
Mineral mix.	1.00	1.00	NFE	41.49	41.50
Table salt	0.30	0.30	Fibre	3.18	7.37
			Lipid	5.00	5.08
			DE	3348.56	3193.67
Value of objective function	24.03	5.31	Ca/P	0.57	0.42

4.4 Feed formulation for catfish fry

All the constraints given in Table-6 were used for feed formulation for fry of catfish. With Kochi market price as the cost of the ingredients optimum solution using linear programming was obtained after 12 iterations. The selected ingredients are Rice bran (16.60%), Sunflower oil cake meal (21.85%), Sorghum meal (4.94%), Poultry byproduct meal (37.96%), and Hydrolyzed feather meal (10.66%). The total cost of the ingredients comes to Rs. 7.65. When Tuticorin market price was set as the cost of ingredients it took 14 iterations to arrive at the optimum solution through linear programming and the selected ingredients under this are Sunflower oil cake meal (0.17%), Cottonseed cake meal (15.00%), *Eichhornia* meal (21.48%), Poultry byproduct meal (54.65%), and Hydrolyzed feather meal (0.70%) with Rs. 5.87 as the total cost of the ingredients. For Bhubaneswar market price as the cost of ingredients, optimum solution was obtained after 14 iterations and the selected ingredients are Sunflower oil cake meal (13.85%), *Eichhornia* meal (24.79%), Poultry byproduct meal (51.29%), and Hydrolyzed feather meal (2.07) with Rs. 3.31 as the total cost of the selected ingredients. Details regarding availability of different nutrients in the dry formula obtained with Kochi, Tuticorin and Bhubaneswar market price are given in Tables 24, 25 and 26 respectively.

Table-24: Formula of pellet feed for fry of catfish for Kochi market price

Formula	%	Nutrients in feed	Total in feed mix.
Rice bran	16.60	Protein	44.65
Sunflower oil cake meal	21.85	Arg	3.52
Sorghum meal	4.94	Hist	0.86
Poultry byproduct meal	37.96	Ile	2.05
Hydrolyzed feather meal	10.66	Leu	3.50
Fish oil or Soybean oil	6.00	Lys	1.98
Vit.c+ Mineral premix.	1.60	Met	0.81
Binder	0.40	Phe	1.75
		Thre	1.78
		Try	0.41
		Val	2.66
		NFE	19.47
		Fibre	8.00
		Lipid	10.00
		DE	3227.01
Value of objective function	7.65	Ca/P	0.97

Table-25: Formula of pellet feed for fry of catfish for Tuticorin market price

Formula	%	Nutrients in feed	Total in feed mix.
Sunflower oil cake meal	0.17	Protein	44.70
Cottonseed cake meal	15.00	Arg	3.26
Eichhornia meal	21.48	Hist	0.89
Poultry byproduct meal	54.65	Ile	1.93
Hydrolyzed feather meal	0.70	Leu	3.24
Fish oil or Soybean oil	6.00	Lys	2.31
Vit.c+ Mineral premix.	1.60	Met	0.81
Binder	0.40	Phe	1.75
		Thre	1.65
		Try	0.41
		Val	2.34
		NFE	18.16
		Fibre	7.50
		Lipid	10.00
		DE	3193.84
Value of objective function	5.87	Ca/P	1.37

Table-26: Formula of pellet for fry of catfish for Bhubaneswar market price

Formula	%	Nutrients in feed	Total in feed mix.
Sunflower oil cake meal	13.85	Protein	43.54
Eichhornia meal	24.79	Arg	3.24
Poultry byproduct meal	51.29	Hist	0.89
Hydrolyzed feather meal	2.07	Ile	2.03
Fish oil or Soybean oil	6.00	Leu	3.45
Vit.c+ Mineral premix.	1.60	Lys	2.29
Binder	0.40	Met	0.87
		Phe	1.75
		Thre	1.73
		Try	0.41
		Val	2.45
		NFE	18.99
		Fibre	8.00
		Lipid	10.00
		DE	3170.96
Value of objective function	3.31	Ca/P	1.36

4.5 Feed formulation for Milkfish fry

Constraints given in Table-7 were used for feed formulation for fry of Milkfish (*Chanos chanos*). With Kochi market price as the cost of the ingredients optimum feed formula through linear programming was obtained after 14 iterations leading to the ingredients Rice bran (37.13%), Sunflower oil cake meal (36.51%), Blood meal (2.32%), Meat meal 0.18%), Poultry byproduct meal (0.68%), and Hydrolyzed feather meal (18.18%) with the total cost of all the selected ingredients as Rs. 5.51. Total cost of the ingredients selected through linear programming using Tuticorin market price, as the cost of the ingredients was Rs. 5.40.

Table-27: Formula of pellet feed for fry of Milkfish for Kochi market price

Formula	%	Nutrients in feed	Total in feed mix.
Rice bran	37.13	Protein	40.00
Sunflower oil cake meal	36.51	Arg	3.53
Blood meal	2.32	Hist	0.90
Meat meal	0.18	Ile	1.89
Poultry byproduct meal	0.68	Leu	3.43
Hydrolyzed feather meal	18.18	Lys	1.60
Coconut oil	1.00	Met	0.68
Tri-calcium phosphate	2.00	Phe	1.85
Vit.mix commercial	2.00	Thre	1.80
		Try	0.41
		Val	2.76
		NFE	26.11
		Fibre	13.97
		Lipid	7.00
		DE	2949.69
Value of objective function	5.51	Ca/P	0.32

The optimum solution for this was obtained after 14 iterations. Ingredients selected were Soybean meal (2.23%), Cottonseed cake meal (6.24%), *Eichhornia* meal (41.12%), Poultry byproduct

Table-28: Formula of pellet feed for fry of Milkfish for Tuticorin market price			
Formula	%	Nutrients in feed	Total in feed mix.
Soybean meal	2.23	Protein	42.99
Cottonseed cake meal	6.24	Arg	3.17
Eichhornia meal	41.12	Hist	0.80
Poultry byproduct meal	34.54	Ile	2.00
Hydrolyzed feather meal	10.88	Leu	3.41
Coconut oil	1.00	Lys	2.13
Tri-calcium phosphate	2.00	Met	0.68
Vit.mix commercial	2.00	Phe	1.77
		Thre	1.80
		Try	0.37
		Val	2.57
		NFE	25.00
		Fibre	9.63
		Lipid	7.39
		DE	3103.20
Value of objective function	5.40	Ca/P	1.22

Table-29: Formula of pellet for fry of Milkfish for Bhubaneswar market price			
Formula	%	Nutrients in feed	Total in feed mix.
Sunflower oil cake meal	7.65	Protein	41.75
Eichhornia meal	42.53	Arg	3.12
Poultry byproduct meal	35.15	Hist	0.80
Hydrolyzed feather meal	9.67	Ile	2.01
Coconut oil	1.00	Leu	3.45
Tri-calcium phosphate	2.00	Lys	2.11
Vit.mix commercial	2.00	Met	0.73
		Phe	1.75
		Thre	1.80
		Try	0.36
		Val	2.56
		NFE	25.00
		Fibre	10.05
		Lipid	7.71
		DE	3088.48
Value of objective function	3.61	Ca/P	1.24

meal (34.54%), and hydrolyzed feather meal (10.88%). The ingredients selected with Bhubaneswar market price as the cost of the ingredients through linear programming are Sunflower oil cake meal (7.65%), *Eichhornia* meal (42.53%), Poultry byproduct meal (35.15%) and Hydrolyzed feather meal (9.67%). Total cost of these ingredients is Rs. 3.61. Details regarding availability of different nutrients in the feed formula for the three places are given in Tables 27, 28 and 29.

4.6 Feed formulation for Tilapia fry

For optimization of feed formulation for Tilapia fry, solution through linear programming was attempted using the constraints on nutrients and ingredients given in table-8. The optimum solution was obtained after 12 iterations and the selected ingredients are Rice bran (15.03%), Sunflower oil cake meal (36.18%), Sorghum meal (8.07%), Fish meal (18.00%), and Poultry byproduct meal (13.38%). The total cost of selected ingredients is Rs. 10.35. With the same constraints but the cost of ingredients as the market price at Tuticorin optimum linear programming solution was obtained after 11 iterations.

Table-30: Formula of pellet feed for fry of Tilapia for Kochi market price

Formula	%	Nutrients in feed	Total in feed mix.
Rice bran	15.03	Protein	36.40
Sunflower oil cake meal	36.18	Arg	2.96
Sorghum meal	8.07	Hist	0.90
Fish meal	18.00	Ile	1.78
Poultry byproduct meal	13.38	Leu	3.04
Cod liver oil	1.00	Lys	2.03
Vegetable oil	1.00	Met	0.95
Vit.+Mineral mix	4.33	Phe	1.69
Starch	3.00	Thre	1.55
		Try	0.45
		Val	2.11
		NFE	25.79
		Fibre	10.00
		Lipid	8.00
		DE	2877.70
Value of objective function	10.35	Ca/P	0.87

Table-31: *Formula of pellet feed for fry of Tilapia for Tuticorin* market price			
Formula	%	Nutrients in feed	Total in feed mix.
Sorghum meal	25.05	Protein	42.28
Fish meal	18.00	Arg	2.68
Squid meal	7.55	*Hist*	0.85
Poultry byproduct meal	40.07	Ile	1.82
Cod liver oil	1.00	Leu	3.26
Vegetable oil	1.00	Lys	2.53
Vit. +Mineral mix	4.33	Met	0.95
Starch	3.00	Phe	1.51
		Thre	1.58
		Try	0.41
		Val	2.14
		NFE	25.00
		Fibre	2.09
		Lipid	10.08
		DE	3342.07
Value of objective function	18.44	Ca/P	1.43

Table-32: Formula of pellet feed for fry of Tilapia for Bhubaneswar market price			
Formula	%	Nutrients in feed	*Total in feed mix.*
Sunflower oil cake meal	30.62	Protein	38.51
Sorghum meal	0.30	Arg	2.91
Mustard oil cake	36.71	Hist	1.01
Fish meal	18.00	Ile	1.90
Poultry byproduct meal	5.05	Leu	3.07
Cod liver oil	1.00	Lys	2.10
Vegetable oil	1.00	Met	0.95
Vit. +Mineral mix	4.33	Phe	1.76
Starch	3.00	Thre	1.71
		Try	0.51
		Val	2.18
		NFE	25.00
		Fibre	8.08
		Lipid	8.00
		DE	2912.14
Value of objective function	5.71	Ca/P	0.77

The ingredients selected accordingly are Sorghum meal (25.05%), Fish meal (18.00%), Squid meal (7.55%), and Poultry byproduct meal (40.07%) with the total cost of the ingredients Rs. 18.44. Replacing cost with market price of Bhubaneswar, the optimum solution got after 11 iterations selected the ingredients Sunflower oil cake meal (30.62%), Sorghum meal (0.30%), Mustard oil cake (36.71%), Fish meal (18.00%), and Poultry byproduct meal (5.05%). Total cost of these ingredients is Rs. 5.71. Details regarding availability of different nutrients in these three feed formula are given in Tables 30, 31 and 32.

4.7 Feed formulation for fry of Asian sea bass *(Lates calcarifer)*

For finding feed formula for fry of Asian sea bass three linear programming solutions were tried using market prices of feed ingredients at Cochin, Bhubaneswar and Tuticorin as the cost of ingredients and using the constraints given in Table-9. The optimum solution with Kochi market price was obtained after 12 iterations and the total cost of the ingredients for this solution is Rs. 13.71. The ingredients selected under this are Sunflower oil cake meal (12.92%), *Eichhornia* meal (11.99%), Fish meal (20.00%), Shrimp meal (6.10%), and Poultry byproduct meal (37.24%). It took 11 iterations to get the optimum solution with Bhubaneswar market price and the total cost of the selected ingredients was only Rs. 7.08. Ingredients selected under this are same as that obtained with Kochi market price as cost. For Tuticorin market price the solution was obtained after 12 iterations with selected ingredients as Cottonseed cake meal (18.87%), Fishmeal (20.00%), Shrimp meal (6.75%), Squid meal (2.53%), and Poultry byproduct meal (40.09%). Total cost of the selected ingredients for this feed was Rs. 19.85. Levels of different nutrients available in these two sets of feed formulation are given in Table-33 and Table-34 along with details of ingredients.

Table-33: Formula of pellet for fry of Asian sea bass for Kochi market price			
Formula	%	Nutrients in feed	Total in feed mix.
Sunflower oil cake meal	12.92	Protein	43.53
Eichhornia meal	11.99	Arg	3.04
Fish meal	20.00	Hist	0.94
Shrimp meal	6.10	Ile	2.01
Poultry byproduct meal	37.24	Leu	3.37
Cod liver oil	2.88	Lys	2.58
Soybean oil	2.87	Met	1.01
Vit.mix	4.00	Phe	1.74
Mineral mix	2.00	Thre	1.74
		Try	0.45
		Val	2.37
		NFE	14.28
		Fibre	6.50
		Lipid	10.00
		DE	3042.84
Value of objective function	13.71	Ca/P	1.88

Table-34: Formula of pellet for fry of Asian sea bass for Tuticorin market price			
Formula	%	Nutrients in feed	Total in feed mix.
Cottonseed cake meal	18.87	Protein	48.16
Fish meal	20.00	Arg	3.40
Shrimp meal	6.75	Hist	1.02
Squid meal	2.53	Ile	2.03
Poultry byproduct meal	40.09	Leu	3.35
Cod liver oil	2.88	Lys	2.74
Soybean oil	2.87	Met	1.01
Vit.mix	4.00	Phe	1.86
Mineral mix	2.00	Thre	1.76
		Try	0.49
		Val	2.40
		NFE	10.77
		Fibre	5.26
		Lipid	10.00
		DE	3130.86
Value of objective function	19.85	Ca/P	1.88

4.8 Feed formulation for fry of Grouper

The constraints used for selecting the feed ingredients of feed formulation are given in the Table-10. Using the Kochi market price as cost of ingredients the linear programming solution was obtained after 10 iterations and the selected ingredients are Sunflower oil cake meal (1.47%), Fish meal (20.00%), Poultry byproduct meal (44.20%) and Hydrolyzed feather meal (20.03%) with Rs. 13.98 as the total cost of selected ingredients.

Table-35: Formula of pellet feed for Grouper fry for Kochi market price

Formula	%	Nutrients in feed	Total in feed mix.
Sunflower oil cake meal	1.47000	Protein	56.53
Fish meal	20.00000	Arg	3.99
Poultry byproduct meal	44.20000	Hist	0.97
Hydrolyzed feather meal	20.03000	Ile	2.55
Cod liver oil	6.00000	Leu	4.29
Lecithin	4.00000	Lys	2.77
Mineral mix	4.30000	Met	0.97
Vit.B6	0.00029	Phe	2.01
		Thre	2.28
		Try	0.48
		Val	3.39
		NFE	4.54
		Fibre	1.84
		Lipid	10.80
		DE	3400.01
Value of objective function	13.98	Ca/P	1.59

With the market price at Tuticorin as cost for the ingredients, the linear programming solution was arrived at after 9 iterations and selected ingredients are Fish meal (20.00%), Poultry byproduct meal (59.17%) and Hydrolyzed feather meal (6.53%). Total cost of the selected ingredients in this feed is Rs. 16.07. For Bhubaneswar market price linear programming solution took 10 iterations for convergence leading to ingredients combination same as that for Tuticorin market price and the total cost is Rs. 5.70. For these two sets of feed ingredients formula the nutrients available in the mix are given in Table-35 and Table-36.

Table-36: Formula of pellet feed for Grouper fry for Tuticorin market price

Formula	%	Nutrients in feed	Total in feed mix.
Fish meal	20.00000	*Protein*	52.53
Poultry byproduct meal	59.17000	Arg	3.50
Hydrolyzed feather meal	6.53000	Hist	0.96
Cod liver oil	6.00000	Ile	2.30
Lecithin	4.00000	Leu	3.87
Mineral mix	4.30000	Lys	2.86
Vit.B6	0.00029	Met	1.04
		Phe	1.82
		Thre	1.99
		Try	0.47
		Val	2.87
		NFE	4.85
		Fibre	1.87
		Lipid	12.77
		DE	3400.01
Value of objective function	16.07	Ca/P	1.79

5. DISCUSSION

Many research workers had applied linear programming as a helpful tool in optimizing nutrient requirements for certain formulation of experimental diet for fish. In the present study, considering both nutritional requirement for a particular species and market price of available feed ingredients in different places, feed formulae were obtained. Since the feed formulae obtained through linear programming for a set of given nutrient and ingredient constraints entirely depend on market price of the ingredients, the solutions are likely to change with change in market price. But market price depends on demand and supply. The richness of feed ingredients in terms of the item mentioned as fixed amount are not known for all the 25 ingredients considered and hence were not included for linear programming.

5.1 Linear Programming Formulated Feed of *P. monodon* juveniles

Cholesterol was not added as fixed micronutrient because endogenous cholesterol contents in the ingredients would suffice the requirement (0.17%) for cholesterol in diet of *P. monodon* (Smith *et al.*, 2001). When all the constraints and Kochi market price were considered, the formulated feed has all the nutrients balanced as per requirement of *P. monodon* juveniles but with high level of crude protein as much as 56.04 % against the required minimum level of 40 % in the diet (Table-15), which may pollute the culture system. Anyhow, the bio-available protein content will be less than the crude protein of 56.04 % and since the digestibility coefficients of all the ingredients are not known for the species this could not be found. When protein requirement was kept at the level of 40 %, no feasible solution could be obtained. Also, when the levels of protein were attempted at ≥ 10 %, ≥

15%, ≥ 20 %,..., ≥ 65 %, the optimum combination obtained through linear programming was same as that with ≥ 40 %.

In one of the available commercial feeds for example, 'Higashi 6000 shrimp Feed' for grower reared in semi-intensive type of shrimp farming, the minimum crude protein content of dry pelleted feed is around 45 % [Highashimaru Feeds (India) Ltd., Thuravoor, Cherthala, Alappuzha (Kerala)]. Among the aminoacids, methionine and threonine were found to be limited nutrients in the diet because of their minimum levels in the blend.

The crude protein content of the feed formula without aminoacid constraints is slightly above the minimum required level (41.77%) and except histidine, lysine, methionine and threonine content, all other aminoacids are found to satisfy the requirements. But, it has only Rs. 7.40 as total cost of selected ingredients blend compared to Rs. 37.32 of the fully balanced feed. It clearly indicates that more nutritionally balanced feed costs relatively more.

The 'Higashi 6000 shrimp Feed' has crude fat content of around 8.5 % of dry pellet which is slightly higher than that of feed formulae (in Table-15) with or without aminoacid constraints. The crude fibre contents of formulae are slightly higher than that of the commercial feed (3.4%).

Feed formulae for Tuticorin (Table-16) showed as high as 60.76 % crude protein when all constraints were considered compared to exactly 40 % in the feed, which is not aminoacid balanced feed. The feed, which is not aminoacid balanced is short in aminoacids requirements for histidine, lysine, methionine and threonine but the total cost was only Rs. 5.87, compared to Rs. 42.46 of the fully balanced one.

In the feed formulae for Bhubaneswar (Table-17), without aminoacid balanced feed showed short falls in lysine, methionine and threonine and slightly in histidine content. Of course, this feed was Rs. 25.79 less costly than the feed with aminoacid balanced for Bhubaneswar.

Practical diet for juvenile shrimp, formulated by Millamena and Trino (1994), with the major ingredients namely fish meal (25.0%), soybean meal (25.0%), shrimp head meal (15.0%), bread flour (13.0%) and seaweed (*Gracilaria sp*) (5.0%) was shown to contain crude protein of 41.7%, crude fat of 8.8%, crude fibre of 5.9% and NFE of 29.2%. The crude protein content of this feed is almost equal to that of all the three aminoacid unbalanced feed of Kochi, Bhubaneswar and Tuticorin. But it is not in the case of aminoacid-balanced feeds of all the three places, where crude protein levels in the diet have gone high to balance all the ten essential aminoacids. Again lp formulated feeds (both balanced and unbalanced) of all the three places have lesser crude fibre content than this feed. Like this feed formula, lp formulated all the three aminoacids unbalanced feeds showed higher % of NFE level (even up to 30.0%) unlike the aminoacid balanced feeds where NFE levels are limited to only 10.0%.

5.2 Linear Programming Formulated Feed of *Macrobrachium rosenbergii* juveniles

Aminoacids profile of *Macrobrachium rosenbergii* larvae (i-ix) was used as the aminoacid requirement of juveniles. Crude protein content of aminoacid-balanced feed developed based on Kochi market price is around 53.83 % of dry weight against the minimum requirement of 37.02 %. Essential aminoacids namely isoleucine, phenylalanine and tryptophan, and Ca/P ratio were found to be very limited in the diet. In the case of aminoacid unbalanced feed based on Kochi price for *M. rosenbergii* crude protein content was 41.61% and in this diet aminoacids namely histidine, lysine, methionine, phenylalanine, threonine and tryptophan are short of the required levels and the digestible energy was found to be at the minimum required level. However, cost of this aminoacid unbalanced feed was Rs.12.98 lesser than that of the balanced one.

In Higashimaru Scampi feed for grower animal the minimum crude protein and crude fat level and maximum crude fibre level are 33.7%, 4.5% and 5.62% of the dry pellet respectively whereas, the crude fat and fibre content of both the formulated feed for Kochi price are 5.0% and 4.0% of the dry pellet respectively.

Tuticorin feed formulae of fully aminoacid balanced pellet for growing *M. rosenbergii* juvenile showed as high as 54.86% of crude protein, with phenylalanine being the limited nutrient in the diet. Diet without aminoacid balance has deficiency in aminoacids namely histidine, lysine, phenylalanine and tryptophan. Methionine is balanced at the minimum required level in this diet. To get the diet balanced for the above aminoacids the additional cost required was Rs. 21.64 in that market price.

Bhubaneswar feed for scampi juveniles costs around Rs. 19.04 for its major ingredients in the aminoacid-balanced feed with minimum level of isoleucine and phenylalanine. Although the levels of arginine, isoleucine, leucine and valine were balanced automatically in the unbalanced diet, the digestible energy was balanced at the minimum required level. The unbalanced diet cost was only Rs. 6.51 for its major ingredients.

5.3 Linear Programming Formulated Feed of Rohu fry

The Kochi formula of aminoacid-balanced feed for Rohu fry (Table-21) is balanced with methionine, phenylalanine and threonine at the minimum required level, and has the crude fibre content of about 3.18% of the dry diet. Also, it has a lipid content of 5.0%. The aminoacid-unbalanced feed has fibre and lipid content 7.87% and 5.0% respectively. Threonine was found to be in balance at minimum in this diet. To get histidine, lysine, methionine and phenylalanine content in balanced condition in the diet, the additional cost was as high as Rs. 20.20 per kilogram at Kochi market price of the ingredients.

In Tuticorin feed formula of nutritionally balanced dry feed for Rohu fry, methionine, phenylalanine and threonine are present at minimum specified level. In unbalanced feed, on the other hand, phenylalanine and threonine levels are found to be slightly less than the minimum required levels but deficient with not only methionine but also histidine and lysine contents. The aminoacid-unbalanced feed would be Rs. 21.74 less costly than the balanced one in that market. Of course, the crude fibre content of this feed is higher (6.55%) than that of the balanced one (2.32%).

The aminoacid-unbalanced diet at Bhubaneswar market price was found to be well balanced in arginine, isoleucine, leucine, tryptophan and valine but is slightly short in threonine level. In this diet the Ca/P ratio was found to be critical (close to the minimum required level) among all the nutrients. The unbalanced diet was Rs. 18.72 less costly than the balanced one in this market.

Nutritional composition of feed for Indian carp (Rohu) fry, formulated by Mohanty and Narayanaswamy (1986) was shown as protein of 29.0%, fat of 12.0% carbohydrate of 9.8% and crude fibre of 17.27% when formulated with ground nut oil cake (60.0%), rice bran (30.0%) and blood meal (10.0%). Compared to this, the solutions obtained through linear programming in this study showed very low fibre content in all the formulated feed Rohu fry. Of course the requirement for carbohydrate was kept high as much as 41.5% of the dry diet because the ratio of carbohydrate to lipid in diet is known to be good at

8.3. Also, the dietary lipid level of 5.0% is considered to be good as far as the growth and feed conversion of Rohu fingerling are concerned (Anwar and Jafri, 2001).

5.4 Linear Programming Formulated Feed of catfish fry

Dry pellet for catfish fry formulated for Kochi price has carbohydrate level and Ca/P ratio at 19.47% and 0.97 respectively. Among all aminoacids, methionine was found to be most limited nutrient for both Kochi and Tuticorin feed formulae. The Ca/P ratio in both Tuticorin and Bhubaneswar feed formulae are almost similar and higher than the Ca/P ratio in Kochi feed formula. The NFE content in all the three feed formulae based on Kochi, Tuticorin and Bhubaneswar market prices are almost equal. Among all the market prices, the linear programming formulated and nutritionally balanced feed of Bhubaneswar was found to be cheapest.

Khan *et al.* (1996) showed that diet containing 42.00% of protein was found to be the best for tropical freshwater catfish *Mystus nemurus* when it was formulated through computerized linear programming. But in this study, all the feed formulated for catfish fry at different market prices showed slightly higher level of protein in the diet.

5.5 Linear Programming Formulated Feed of Milkfish fry

Kochi feed formula showed that lysine, methionine and threonine among the aminoacids and lipid level are balanced at the minimum required levels in the diet having fibre content and Ca/P ratio at 13.97% and 0.32 respectively whereas histidine, methionine and threonine are in limited quantity in Tuticorin feed having 9.63% and 1.22 as crude fibre and Ca/P ratio respectively. Histidine and threonine levels in Bhubaneswar feed are balanced but at the minimum required levels.

Kochi feed was the costliest among the three feeds having Rs. 5.51 as the total cost of selected ingredients mix.

In the feed for milkfish fry, formulated by Alava and Lim (1988), with fish meal (30.0%), shrimp head meal (8.0%), soybean meal (10.0%), meat and bone meal (6.71%), corn gluten meal (10.2%), rice bran (12.1%) and wheat flour (15.9%) as major ingredients, the nutritional compositions were shown as crude protein of 40.7%, crude fat of 8.4%, crude fibre of 4.2% and NFE of 31.2%. In comparison to this feed, all the three formulated feeds for Milkfish fry in the present study, through linear programming using market prices at Kochi, Tuticorin and Bhubaneswar, are high in crude fibre content but with lower NFE content.

In the practical diet formula for juvenile milkfish, formulated by Sumagaysay *et al.* (1991), with fish meal (10.0%), soybean meal (35.0%), copra meal (14.0%), wheat pollard (18.0%) and rice bran (18.0%) as major ingredients, the nutritional compositions were shown as crude protein of 27.4%, crude fat of 6.0%, crude fibre of 7.2% and NFE of 50.6%. In comparison to this feed, all the three lp formulated aminoacids balanced feeds have higher % of crude protein, fat and fibre content and lower % of NFE content in the diets. Although the minimum requirement of NFE % in the diet of milkfish fry was set at 25.0%, all the lp solutions could not come out with higher % of NFE level in all the three diets of three different places.

5.6 Linear Programming Formulated Feed of Tilapia fry

Among all three feeds for Tilapia fry formulated through linear programming, Tuticorin feed has lowest level of fibre content and hence was costliest (Rs. 12.73 and Rs. 8.09 more costly than feed of Bhubaneswar and Kochi respectively). Methionine level among all the aminoacids was found to be at the minimum required level in all types of feed. Ca/P ratio in the diet is more for Tuticorin feed.

The nutritional compositions of practical diet for larval Nile Tilapia (nursery), formulated by Santiago *et al.* (1982), with fish meal (30.17%), soybean meal (25.95%), copra meal (11.48%), rice bran (14.97%) and Ipil-ipil leaf meal (8.1%) as major ingredients (the minor ingredients were same as the fixed amount of this present study) were shown as *crude protein* (38.1%), *crude fat* (8.7%), *crude fibre* (5.6%) and NFE (30.8%). The protein contents of all the three lp formulated aminoacid balanced feeds are obviously similar to this feed.

5.7 Linear Programming Formulated Feed of Asian Sea bass fry

For *all* the three types of feed of Asian Sea bass fry, *methionine content and Ca/P level were found to be at the minimum* required level of 1.01 and 1.88 respectively. Pellet of Kochi and Bhubaneswar formulae have the level of histidine of 0.94%, isoleucine of 2.01%, leucine of 3.37%, phenylalanine of 1.74%, threonine of 1.74%, valine of 2.37% and crude fibre of 6.5% in the diet whereas, levels of these nutrients in Tuticorin formula are 1.02%, 2.03%, 3.35%, 1.86%, 1.76%, 2.4% and 5.26% respectively in the diet. Nutritional requirements of these nutrients were not used for formulation of feed for the species through linear programming. Tuticorin feed was found to be the costliest among all the three.

Diet formulated for juvenile sea bass, with fish meal (42.0%), soybean meal (9.0%), shrimp meal (*Acetes* sp.) (10.0%), squid meal (5.0%), rice meal (14.5%) and bread flour (7.75%) as major ingredients (the minor ingredients were same as fixed amount in this study) was shown to contain crude protein, fat and fibre of 43.0%, 9.0% and 12.0% respectively with NFE level of 25.0% in the diet (Bautista *et al.*, 1994). The protein and lipid levels of lp formulated aminoacid balanced feeds based on Kochi, and Bhubaneswar market price are similar to that of this feed in which comparatively higher levels of crude fibre and NFE were present.

5.8 Linear Programming Formulated Feed of Grouper fry

Methionine level in the pellet feed for Grouper fry, formed based on Kochi market price is found to be at the minimum required level in the diet whereas the digestible energy content of all the feed formulation is balanced at the minimum required level. The feed formula based on Bhubaneswar market price was found to be cheapest among all the three.

In the feed formulations obtained for juveniles of *P. monodon* using market prices of Kochi, Tuticorin and Bhubaneswar without considering essential aminoacid requirements it was found that it meets requirements of 6 out of the 10 essential aminoacids but deficient in histidine, lysine, methionine, and threonine. Among these four, except methionine, all others are met to some extent (more than 65% of the required level). If this deficiency can be sacrificed, it is very much economical and efficient to recommend the feed formulations obtained by removing aminoacid constraints from the linear programming solution set up.

In the case of *M. rosenbergii* juveniles, the feed formulae obtained based on Kochi and Bhubeneswar market prices without considering the essential aminoacid requirements are deficient in histidine, lysine, methionine, phenylalanine, threonine and tryptophan whereas the feed formulae based on Tuticorin market prices is deficient only in four of these except methionine and threonine. But among these except phenylalanine all other amino acid requirements are met by these feed formulae to some extent (more than 55% of the required level). Tuticorin feed formula is mainly deficient in phenylalanine and all other aminoacid requirements are met above 72% of their required level. Hence, for Tuticorin it is better to choose the feed formulation obtained without aminoacid constraints if the deficiency in phenylalanine in the feed can be tolerated considering the drastic reduction in the cost.

The feed formula suggested based on linear programming for Rohu fry without essential aminoacid constraints based on Tuticorin and Bhubaneswar market prices are deficient in histidine, lysine, methionine, phenylalanine, threonine and that based on Kochi market prices are deficient in four of the above except threonine. But, out of the five deficient aminoacids four are met above 68% and 76% of the required levels respectively in Tuticorin and Bhubaneswar feeds. Hence, for Tuticorin and Bhubaneswar these feed formulae may be preferred over the fully aminoacid balanced ones considering the reduced cost to the level of even one fifth of the cost of the fully balanced feed.

SUMMARY

This study was carried out to formulate nutritionally balanced feed for Tiger shrimp (*Penaeus monodon*) juveniles, Scampi (*Macrobrachium rosenbergii*) juveniles, Rohu (*Labeo rohita*) fry, Catfish fry, Milkfish (*Chanos chanos*) fry, Tilapia fry, Asian sea bass (*Lates calcarifer*) fry and Grouper fry, based on their nutritional requirements, at the least possible cost considering market prices at three different places namely Kochi, Tuticorin and Bhubaneswar. Twenty-five feed ingredients were considered for feed formulation through linear programming. Nutritional requirements of the species and nutritional compositions of these ingredients in terms of sixteen nutrients and different market prices of these feed ingredients were collected and for linear programming. Different feed formulae were obtained as solution of linear programming set based on market prices at these three places for each of the species separately, considering their nutritional their requirement. Also, for first three species feed formulae were obtained by relaxing the ten essential aminoacids requirements.

In the feed formulation for juveniles of Tiger shrimp at Kochi market price, the solution yielded a combination with only 5 feed ingredients out of twenty-five, costing Rs. 37.32 and when the constraints were released by removing ten essential aminoacid constraints, the formulation was composed of 4 ingredients with only Rs. 7.40 as cost. The feed formula obtained without ten aminoacid constraints had 6 aminoacids at required levels. For Tuticorin market price, the combination of feed formula consisted of 5 ingredients with cost of Rs. 42.46 and 4 ingredients with cost of only Rs. 5.87 for solution with and without aminoacid constraints respectively and the aminoacid unbalanced feed formula had 6 aminoacids in balanced condition. For Bhubaneswar market price, the selected ingredients are same as in the case with Kochi market price but with a different total cost of Rs. 29.84. Without aminoacid constraints, 5 ingredients were

selected with only Rs. 4.05 as the cost and the formula was balanced with 6 aminoacids. Aminoacid balanced feed formulae of Kochi and Tuticorin market price showed higher level of crude protein.

Aminoacid balanced feed formulation for Scampi juveniles at Kochi price consisted of 8 ingredients costing Rs. 19.51 whereas the unbalanced feed formula consisted of 6 ingredients costing of Rs. 6.53 and in balance for 4 aminoacids. Formula based on Tuticorin market price consisted of 5 ingredients in both aminoacid balanced and unbalanced feed with respective costs Rs. 29.32 and 7.86. The aminoacid unbalanced formula showed deficiency in only 4 aminoacids. Both the aminoacid balanced and unbalanced formula based on Bhubaneswar price consisted of 6 ingredients with costs Rs. 19.04 and Rs. 6.51 respectively. The unbalanced one was deficient of 6 aminoacids.

Aminoacid balanced formula for Rohu fry at Kochi price had 6 ingredients with a cost of Rs. 25.43 whereas, the unbalanced one had 4 ingredients costing Rs. 5.23 only, but was deficient of 4 aminoacids. Tuticorin formula yielded 6 ingredients with Rs. 27.41 as the cost and 4 ingredients with Rs. 5.67 as cost, respectively for aminoacid balanced and unbalanced feed. The unbalanced feed was defiecient of 5 aminoacids. In Bhubaneswar formula, the ingredients selected were same as that obtained with Kochi market price when all the constraints were used but the total cost of the ingredients was Rs. 24.03 whereas, without aminoacid constraints 5 ingredients formed the solution with only Rs. 5.31 as the cost but is deficient of 5 aminoacids.

Feed formula for catfish fry at both Kochi and Tuticorin price consisted of 5 ingredients but with different cost of Rs. 7.65 and 5.87 respectively. The Bhubaneswar formula yielded 4 ingredients with Rs. 3.31 as the cost.

Feed formulae based on market price at Kochi, Tuticorin and Bhubaneswar for milkfish fry consisted of 6 ingredients costing Rs. 5.51, 5 ingredients costing Rs. 5.40 and 4 ingredients costing Rs. 3.61 respectively.

The least cost feed formulae based on market price at Kochi and Bhubaneswar for Tilapia yielded 5 ingredients each with Rs. 10.35 and Rs. 5.71 respectively as costs whereas the Tuticorin formula had 4 ingredients with cost as high as Rs. 18.44.

Feed formulae for fry of Asian sea bass had linear programming solution consisting of only 5 ingredients for all the three places. Feed formula was same for Kochi and Bhubaneswar market prices and the total cost of ingredients were Rs. 13.71 and Rs. 7.08 respectively. At Tuticorin market price the feed formula had a cost of Rs. 19.85.

The feed formulae for Grouper fry at Bhubaneswar and Tuticorin market prices had the same 3 ingredients costing of Rs. 5.70 and 16.07 respectively whereas, feed formula for Kochi market price consisted of 4 ingredients costing Rs. 13.98.

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